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# A STUDY OF MUSCLE FORCES AND FATIGUE



*PAUL A. HUNSICKER*

*UNIVERSITY OF MICHIGAN*



*DECEMBER 1957*

AERO MEDICAL LABORATORY
CONTRACT NO. AF 33(616)-3461

WRIGHT AIR DEVELOPMENT CENTER
AIR RESEARCH AND DEVELOPMENT COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

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# A STUDY OF MUSCLE FORCES AND FATIGUE

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PROJECT 7214
TASK 71727

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AIR RESEARCH AND DEVELOPMENT COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

Carpenter Litho & Prtg. Co., Springfield, O.
700 — March 1958

# FOREWORD

The research project was conducted at the University of Michigan under the authority of Contract No. AF 33(616)-3461 with Paul A. Hunsicker as the Principal Investigator. The Kinematic Muscle Study machine used in conducting these tests was developed in the Anthropology Section of the Aero Medical Laboratory. The Kellogg Universal Dynamometer used for a few of the strength tests belongs to the Physical Education Research Laboratory at the University of Michigan. Mr. H. T. E. Hertzberg served as Project Engineer for the Aero Medical Laboratory.

ABSTRACT

The first phase of the research deals with the strength test results taken on 30 subjects covering 120 strength tests. The subjects were seated in a simulated pilot-seat and six movements were tested. The results are presented in percentile tables and graphic form. The next part of the study involves data on 25 subjects who were tested to determine the amount of strength possible in wrist pronation and wrist supination. The final phase of the research gives information on the strength-decrement over a 42-hour period in which the subjects were tested hourly. Several recommendations are offered.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

Jack Bollerud

JACK BOLLERUD
Colonel, USAF (MC)
Chief, Aero Medical Laboratory
Directorate of Laboratories

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## SECTION I

## INTRODUCTION

The idea of determining the strength which an individual could exert while seated in a simulated pilot-seat was suggested several years ago by Mr. Hertzberg, Chief of the Anthropology Section, Biophysics Branch, Aero Medical Laboratory, Wright Air Development Center. Discussions between Mr. Hertzberg and the author resulted in the planning of several research projects.

An earlier investigation by the author (7)* was concerned with:

1. A survey of the literature dealing with the measurement of human strength.

2. Experimenting with the Kinematic Muscle Study machine to make it functional.

3. Testing an adequate sample of men to determine how much arm strength they could exert with the body and arms in selected positions.

To continue the exploration in the field of human strength, the present research will be divided into the following parts:

1. Testing an adequate sample of men with the Kinematic Muscle Study machine to determine the strength which they can exert with the arms and hands in selected positions.

2. Testing an adequate sample of men to determine the strength which they can exert in wrist pronation and wrist supination.

3. Testing a small sample of men hourly for 42 test periods to determine the strength-decrement during this period.

## SECTION II

## STRENGTH IN SITTING POSITION, ARMS VERTICALLY DOWN

Although the Kinematic Muscle Study machine was in good working order at the conclusion of the previous study, the

*Numbers in parentheses refer to the Bibliography

Manuscript submitted in October 1957 for publication as a WADC Technical Report.

dynamometers, supporting structure, electrical system and recording camera were all rechecked. The dynamometers were recalibrated and the new readings appear in Appendices A through F.

## Description of Tests

The test battery used in this phase of the research was divided into two parts; namely, tests in the sitting position with the hands pronated and tests in the sitting position with the hands supinated. Except in rare instances these were given on separate days and within a week of each other. The subject was oriented with the apparatus by running some trial tests. None of the testees had any difficulty comprehending the verbal instructions which were given at the first period of testing. The tests were administered in the following manner:

1. Sitting position, arms extended vertically down, elbows at 180°, wrists pronated and in a perpendicular line with the external canthus, hands grasping dynamometers (Fig. 1). With the subject in this position, a series of six strength tests was made on each hand. Each test lasted five seconds, and one minute rest was allowed between tests. The following sequence was adhered to:

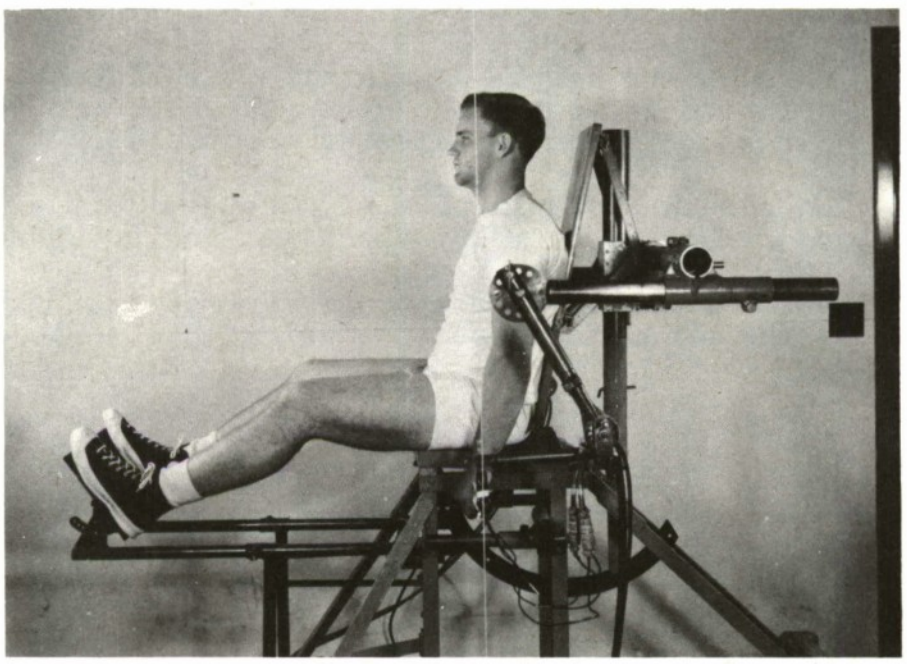


Fig. 1. Wrists Pronated, Elbows 180°

(a) On a signal "go" from the examiner the subject pushed forward with the right hand as hard as possible for five seconds. The examiner did the timing and told the subject to stop at the end of five seconds. During the test the examiner took three single-frame exposures of the trial. These were usually taken at the two-second, three-second, and four-second intervals. Since the examiner was able to watch the indicators during the test it was possible to record the maximum effort in all instances.

(b) The second test was to pull back on the right dynamometer with the right hand. The same procedure as in (a) was repeated for timing and recording the test result.

(c) The third test consisted of pulling up on the dynamometer.

(d) The subject pushed forward on the left hand dynamometer in a manner similar to (a).

(e) In the next test the subject pulled back on the left dynamometer with the left hand.

(f) The subject pulled up on the left hand dynamometer.

(g) The subject pushed down on the right hand dynamometer.

(h) The subject abducted the right arm, or pulled away from the mid-line.

(i) The subject adducted the right arm, or pulled toward the mid-line.

(j) The testee pushed down on the left hand dynamometer.

(k) The testee abducted the left arm, or pulled away from the mid-line.

(l) The subject adducted the left arm, or pulled toward the mid-line.

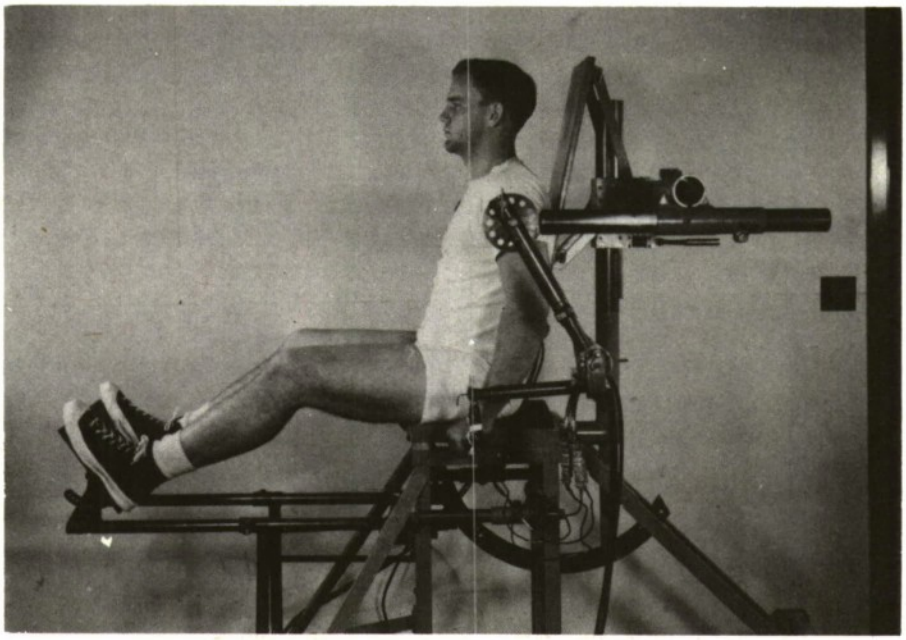


Fig. 2. Wrists Pronated, Elbows 150°

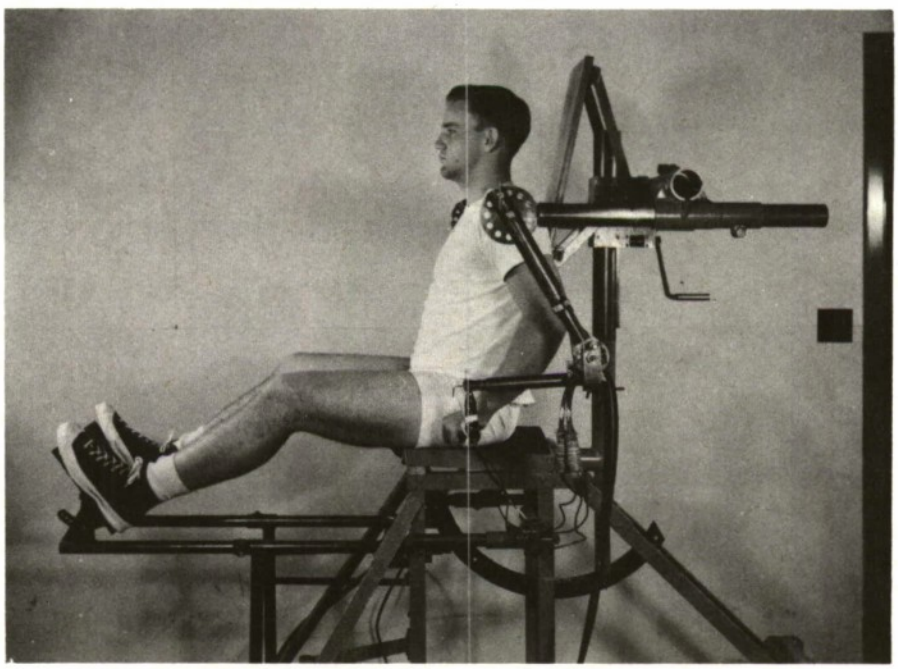


Fig. 3. Wrists Pronated, Elbows 120°

2. After tests (1a) through (1ℓ) were given, the Kinematic Muscle Study machine was adjusted so as to fix the subject's elbows at 150° of flexion (Fig. 2). The same 12 tests were then administered at the new position.

3. The machine was adjusted and the 12 tests given with the subject's elbows at 120° (Fig. 3).

4. The machine was changed so the subject's elbows were at 90°, and the tests were given (Fig. 4).

5. The machine was adjusted so the subject's elbows were at 60°, and the tests administered (Fig. 5).

The sixty tests with the subject's wrists pronated were given in one test session. A second test period was required to administer the tests with the wrists supinated. The same procedure and test sequence was used with the wrists supinated as in the pronated position.

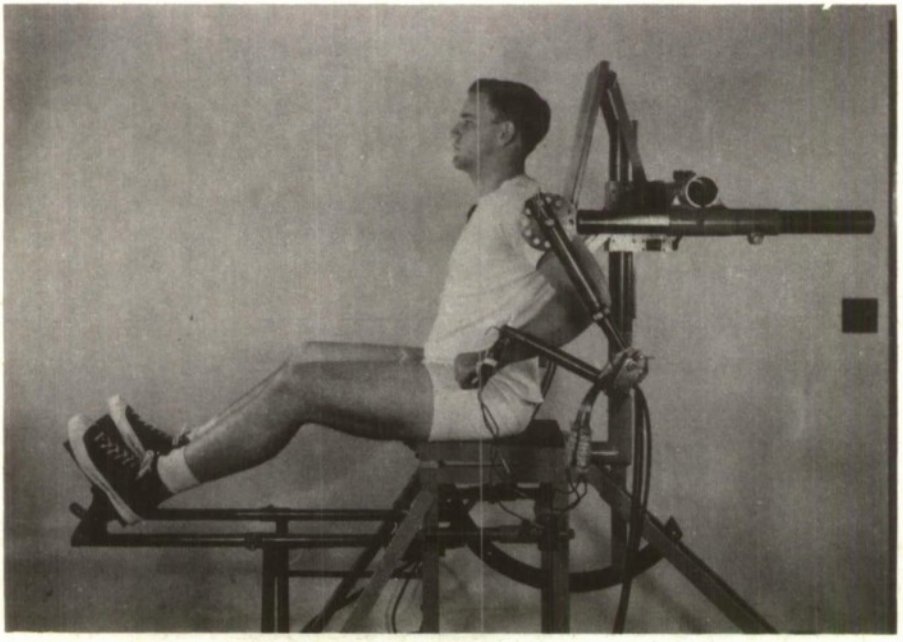


Fig. 4. Wrists Pronated, Elbows 90°

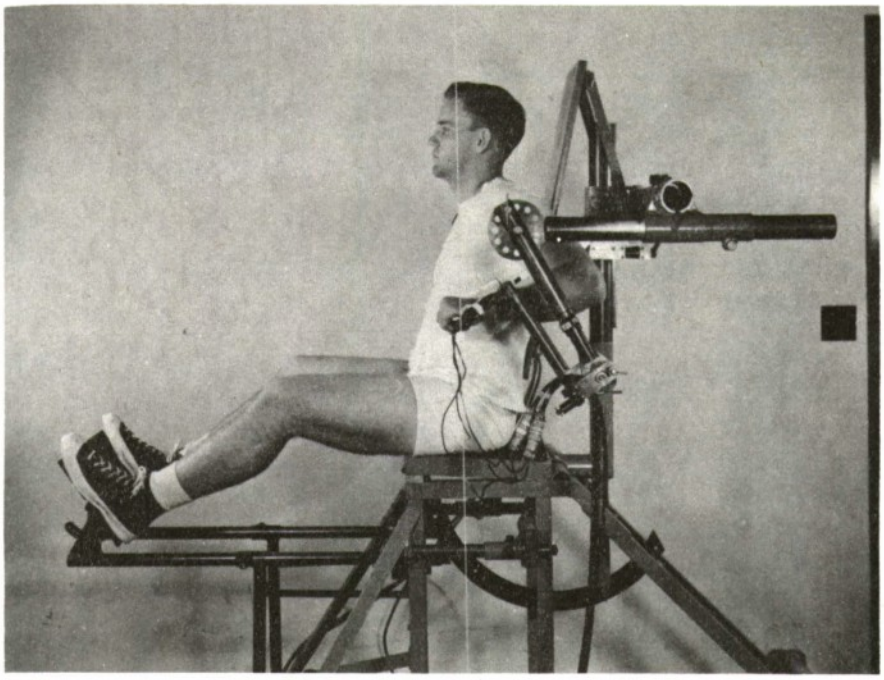


Fig. 5. Wrists Pronated, Elbows 60°

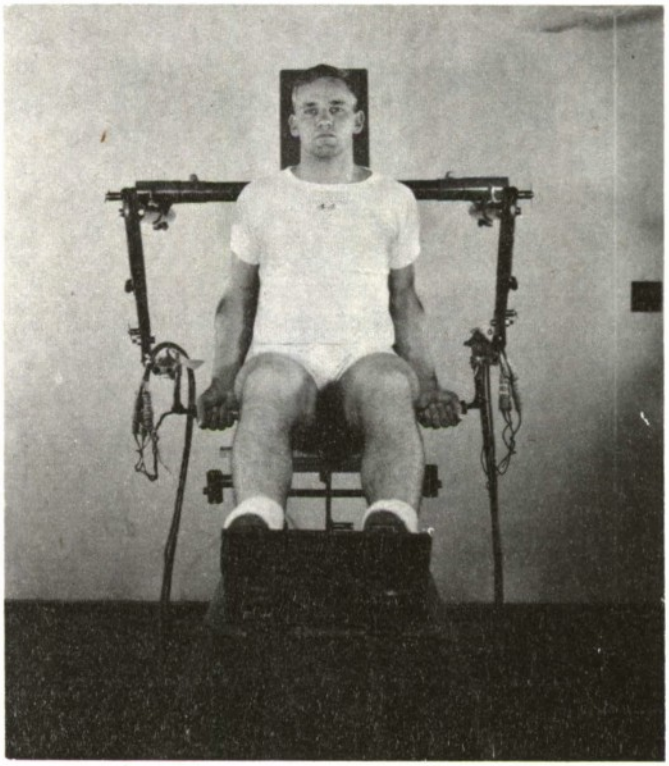


Fig. 6. Front View, Wrists Supinated

## Subjects Tested

The subjects tested in this phase of the research were all students at the University of Michigan ranging in age from 18 to 27 years, or comparable to the age-span of a pilot trainee group. In selecting the sample an attempt was made to span the physical characteristics as outlined in the Hertzberg, Daniels and Churchill report Anthropometry of Flying Personnel-1950 (6).

An examination of Table 1 reveals that the anthropometric measurements of the testees were well within the range of the limits found in flying personnel. The subjects were selected with the thought of spanning the range of physical characteristics as it was desirable to determine the range of human strength.

All subjects were paid volunteers and the examiners felt that the testees were exerting maximum efforts during the test periods. The group was equally cooperative in keeping appointments at the scheduled times.

TABLE 1

PHYSICAL CHARACTERISTICS OF SUBJECTS

| | Low Score | High Score | Mean | Sigma |
|---|---|---|---|---|
| Age (years) | 18 | 27 | 22.8 | 2.9 |
| Weight (lbs.) | 126 | 206 | 156.5 | 17.3 |
| Height (ins.) | 64 | 74.5 | 69.2 | 3.5 |
| Chest Cir. relaxed | 32 | 41.2 | 36.6 | 2.2 |
| Chest Cir. expanded | 33.1 | 42.7 | 38.7 | 2.6 |
| Waist Cir. | 27.6 | 38.0 | 31.1 | 5.0 |
| Biceps flexed | 10.5 | 15.2 | 12.6 | 0.7 |
| Lower Arm Cir. flexed | 9.8 | 12.5 | 11.2 | 1.2 |
| Wrist Cir. | 6.1 | 7.6 | 6.8 | 0.8 |
| Wrist to Knuckle | 2.3 | 3.1 | 2.8 | 0.3 |
| Shoulder Breadth (Biacromial) | 14.5 | 17.4 | 16.2 | .01 |

## SECTION III

## STRENGTH TEST RESULTS

In the analysis of the results three strength scores were available for each test. Since the dynamometers gave readings in three axes, a resultant force had to be calculated and the highest resultant was selected for describing the data. All tables and figures in this section are based on the highest of the three resultants for any given test.

Wrists Pronated, Forward Push (Table 2, Fig. 7)

In this action, the greatest strength was exerted with the elbows at 60° (right and left arms). Strength was progressively less in both arms with the elbows at 90, 120, 150 and 180° and the graphs ran parallel. The lowest score for the best position with the right arm was 30 pounds, and for the left arm, 32 pounds. Approximately two-thirds of the cases pulled between 58 and 130 pounds (right) and 51 and 121 (left). The weakest pull with the elbows at 60° was 17 percent (right) and 18 percent (left) as strong as the strongest.

Wrists Pronated, Pull Back (Table 3, Fig. 8)

The strength developed in this action was relatively small with the greatest amount when the elbows were at 60°. Approximately two-thirds of the sample pulled between 21 and 53 pounds (right) and 21 and 57 pounds (left). The range of 11 to 107 pounds (right) and 19 to 100 pounds (left) made it apparent that there are tremendous individual differences. The degree of elbow flexion did not have a marked effect on these scores. The curves for the right and left arms ran fairly parallel.

Wrists Pronated, Pull Up (Table 4, Fig. 9)

Unlike the previous tests, the greatest force could be exerted in this action with the elbows at 150°. In general the strength decreased as the degrees of elbow flexion approached 60. The scores ranged from 35 to 185 pounds (right) and from 56 to 179 pounds (left). The lowest mean values were 50 percent (right) and 57 percent of the maximum values (left). The middle two-thirds of the distribution ranged between 62 and 138 pounds for the right arm and between 69 and 131 pounds for the left arm.

Wrists Pronated, Push Down (Table 5, Fig. 10)

Although the degrees of elbow flexion did not seem to affect this action to a great extent there were minor differences. In the case of the right arm the maximum effort was achieved with the elbow flexed to 120°. With the left arm the high value was attained with 150° of flexion. The lowest mean value, 81 pounds at 60° was 88 percent of the maximum of 92 pounds at 120°. The variance was even less with the left arm, where the minimum of 74 pounds at 60° was 94 percent of the 79 pound maximum at 150°. The curve for the left arm comes fairly close to approximating a straight line.

Fig. 7. POSITION OF WRIST: PRONATION
DIRECTION OF MOVEMENT: FORWARD

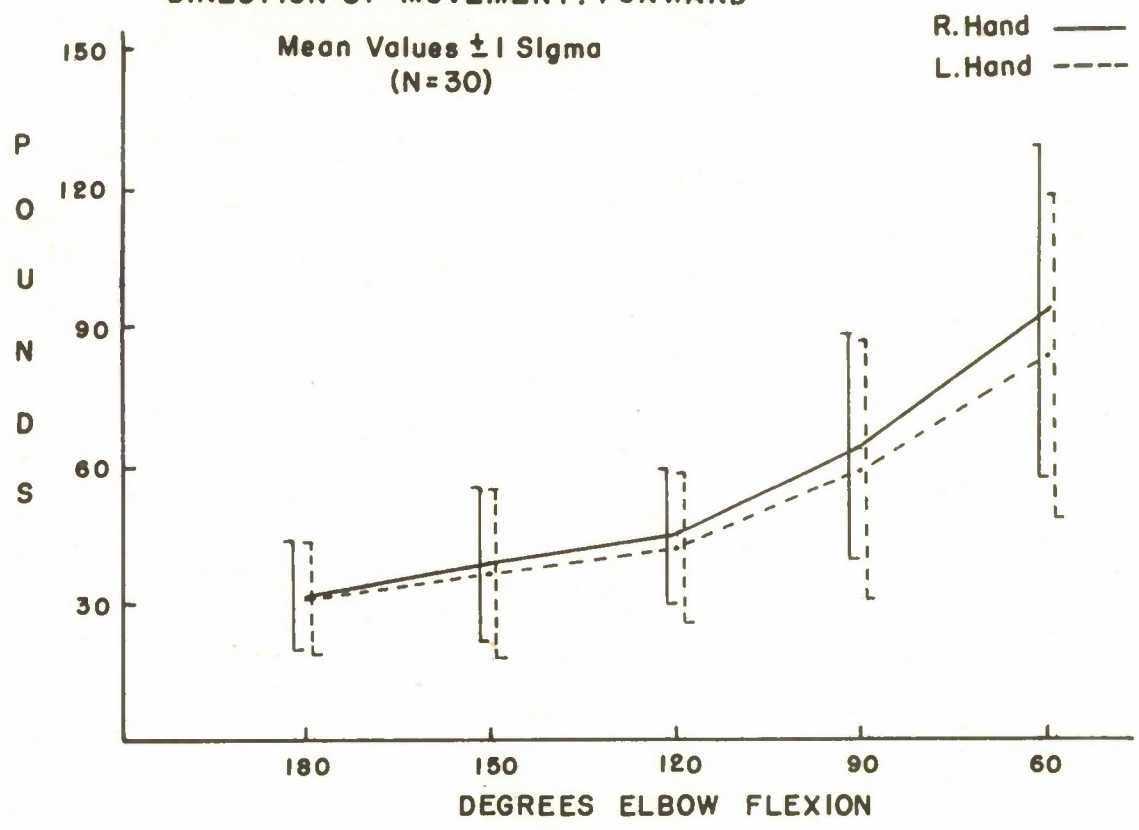



TABLE 2

POSITION OF WRIST: PRONATION
DIRECTION OF MOVEMENT: FORWARD

| %-iles | Elbow Flexion | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Right Arm | | | | | Left Arm | | | | |
| | 180° | 150° | 120° | 90° | 60° | 180° | 150° | 120° | 90° | 60° |
| 5 | 17 | 18 | 23 | 25 | 40 | 12 | 15 | 17 | 27 | 33 |
| 10 | 19 | 21 | 27 | 34 | 52 | 16 | 17 | 21 | 29 | 40 |
| 20 | 23 | 26 | 30 | 45 | 57 | 19 | 20 | 25 | 36 | 49 |
| 30 | 24 | 29 | 33 | 48 | 70 | 22 | 24 | 29 | 43 | 62 |
| 40 | 26 | 31 | 42 | 58 | 78 | 24 | 29 | 32 | 49 | 72 |
| 50 | 27 | 33 | 45 | 64 | 83 | 28 | 30 | 42 | 52 | 80 |
| 60 | 29 | 41 | 47 | 70 | 93 | 34 | 33 | 45 | 54 | 85 |
| 70 | 33 | 44 | 52 | 79 | 111 | 37 | 40 | 48 | 71 | 95 |
| 80 | 42 | 49 | 60 | 82 | 127 | 38 | 57 | 58 | 81 | 113 |
| 90 | 49 | 59 | 63 | 99 | 140 | 55 | 65 | 69 | 91 | 135 |
| 95 | 59 | 66 | 70 | 100 | 156 | 59 | 69 | 71 | 93 | 138 |
| Low Score | 15 | 15 | 20 | 22 | 30 | 9 | 13 | 16 | 26 | 32 |
| High Score | 60 | 92 | 92 | 106 | 172 | 62 | 82 | 86 | 167 | 183 |
| Number | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 |
| Mean | 32 | 40 | 46 | 65 | 94 | 32 | 37 | 43 | 60 | 86 |
| Std. Dev. | 12 | 18 | 15 | 24 | 36 | 13 | 18 | 17 | 28 | 35 |

Fig. 8. POSITION OF WRIST: PRONATION
DIRECTION OF MOVEMENT: BACK

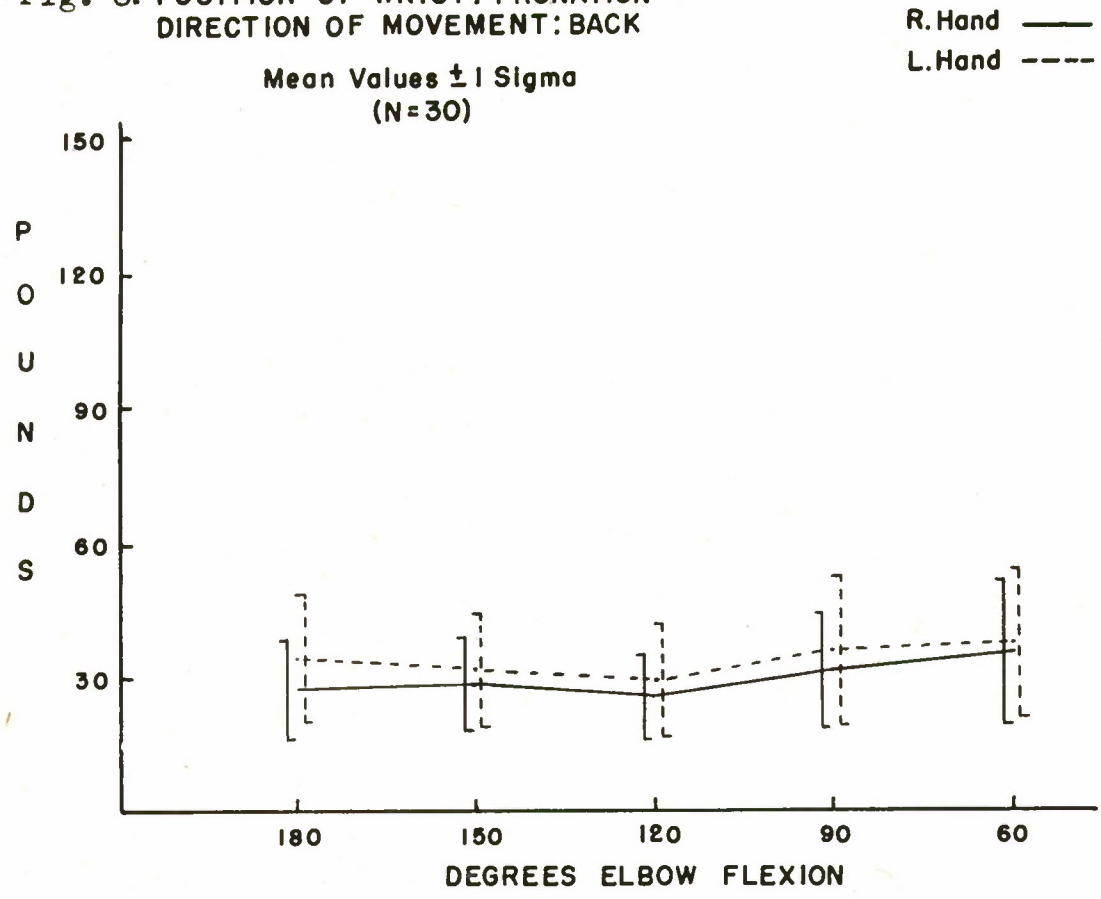



TABLE 3

POSITION OF WRIST: PRONATION
DIRECTION OF MOVEMENT: BACK

| %-iles | Elbow Flexion | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Right Arm | | | | | Left Arm | | | | |
| | 180° | 150° | 120° | 90° | 60° | 180° | 150° | 120° | 90° | 60° |
| 5 | 11 | 12 | 13 | 14 | 13 | 16 | 15 | 12 | 17 | 20 |
| 10 | 14 | 15 | 17 | 18 | 16 | 20 | 20 | 15 | 20 | 22 |
| 20 | 17 | 18 | 19 | 22 | 24 | 22 | 21 | 20 | 22 | 23 |
| 30 | 19 | 20 | 20 | 25 | 29 | 25 | 23 | 23 | 25 | 27 |
| 40 | 22 | 22 | 22 | 27 | 31 | 29 | 26 | 25 | 28 | 32 |
| 50 | 25 | 28 | 24 | 32 | 37 | 29 | 31 | 27 | 32 | 35 |
| 60 | 31 | 30 | 29 | 35 | 39 | 32 | 34 | 29 | 36 | 40 |
| 70 | 35 | 34 | 29 | 36 | 42 | 38 | 37 | 36 | 40 | 45 |
| 80 | 39 | 40 | 34 | 40 | 45 | 43 | 41 | 40 | 45 | 52 |
| 90 | 45 | 41 | 36 | 46 | 49 | 52 | 47 | 48 | 55 | 55 |
| 95 | 48 | 48 | 43 | 54 | 50 | 61 | 52 | 56 | 65 | 64 |
| Low Score | 11 | 8 | 9 | 13 | 11 | 12 | 12 | 9 | 14 | 19 |
| High Score | 53 | 56 | 48 | 67 | 107 | 71 | 72 | 61 | 105 | 100 |
| Number | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 |
| Mean | 28 | 29 | 26 | 32 | 37 | 34 | 32 | 30 | 37 | 39 |
| Std. Dev. | 12 | 10 | 10 | 13 | 16 | 15 | 13 | 14 | 18 | 18 |

Fig. 9. POSITION OF WRIST: PRONATION
DIRECTION OF MOVEMENT: UP

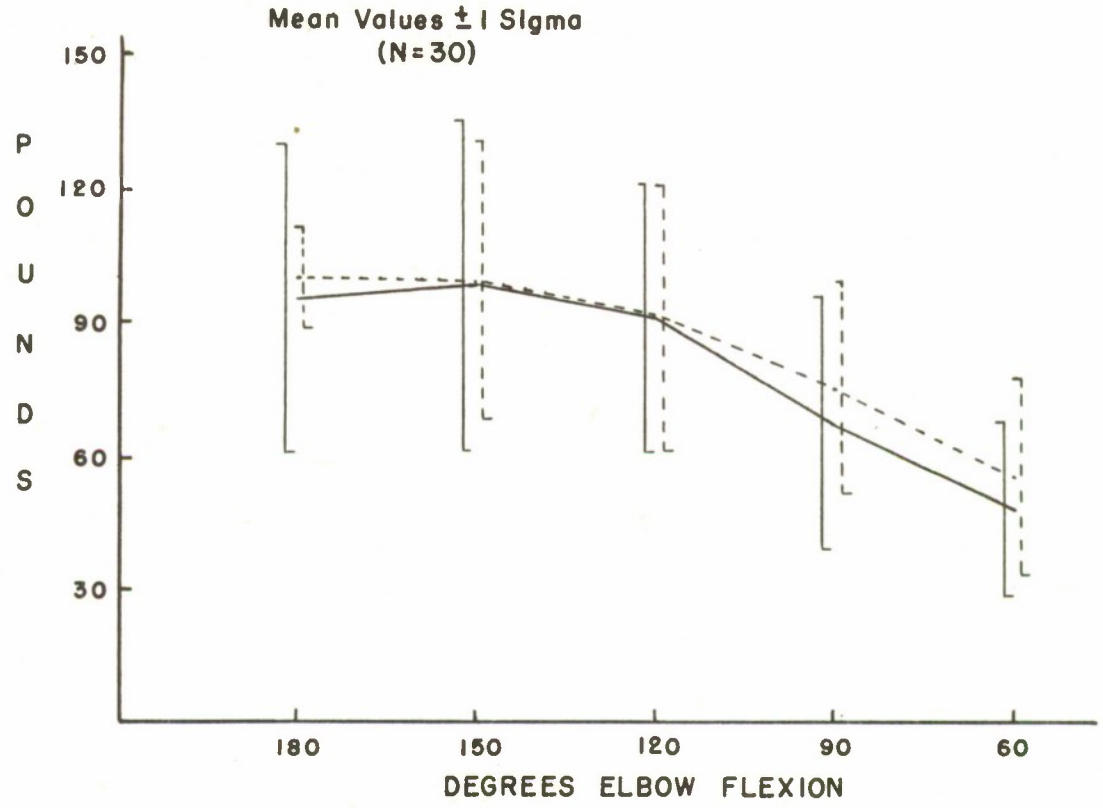



TABLE 4

POSITION OF WRIST: PRONATION
DIRECTION OF MOVEMENT: UP

| %-iles | Elbow Flexion | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Right Arm | | | | | Left Arm | | | | |
| | 180° | 150° | 120° | 90° | 60° | 180° | 150° | 120° | 90° | 60° |
| 5 | 35 | 43 | 41 | 28 | 23 | 47 | 58 | 45 | 37 | 22 |
| 10 | 42 | 57 | 45 | 30 | 25 | 57 | 60 | 57 | 45 | 26 |
| 20 | 66 | 64 | 65 | 45 | 31 | 66 | 73 | 68 | 54 | 39 |
| 30 | 71 | 77 | 75 | 53 | 35 | 85 | 79 | 75 | 61 | 42 |
| 40 | 77 | 80 | 85 | 58 | 42 | 89 | 85 | 80 | 68 | 50 |
| 50 | 91 | 83 | 88 | 69 | 44 | 92 | 89 | 83 | 76 | 53 |
| 60 | 99 | 105 | 96 | 71 | 50 | 106 | 95 | 90 | 79 | 56 |
| 70 | 109 | 118 | 101 | 81 | 59 | 113 | 111 | 99 | 85 | 67 |
| 80 | 122 | 132 | 115 | 92 | 71 | 118 | 128 | 114 | 90 | 72 |
| 90 | 139 | 129 | 127 | 97 | 76 | 138 | 139 | 140 | 110 | 83 |
| 95 | 156 | 165 | 138 | 112 | 79 | 171 | 159 | 145 | 123 | 100 |
| Low Score | 29 | 35 | 39 | 28 | 22 | 38 | 56 | 39 | 30 | 21 |
| High Score | 167 | 185 | 159 | 126 | 83 | 178 | 179 | 149 | 131 | 114 |
| Number | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 |
| Mean | 95 | 99 | 91 | 69 | 49 | 101 | 100 | 91 | 77 | 57 |
| Std. Dev. | 35 | 38 | 30 | 29 | 20 | 11 | 32 | 30 | 24 | 22 |

Fig. 10. POSITION OF WRIST: PRONATION
DIRECTION OF MOVEMENT: DOWN

R. Hand ——
L. Hand ----

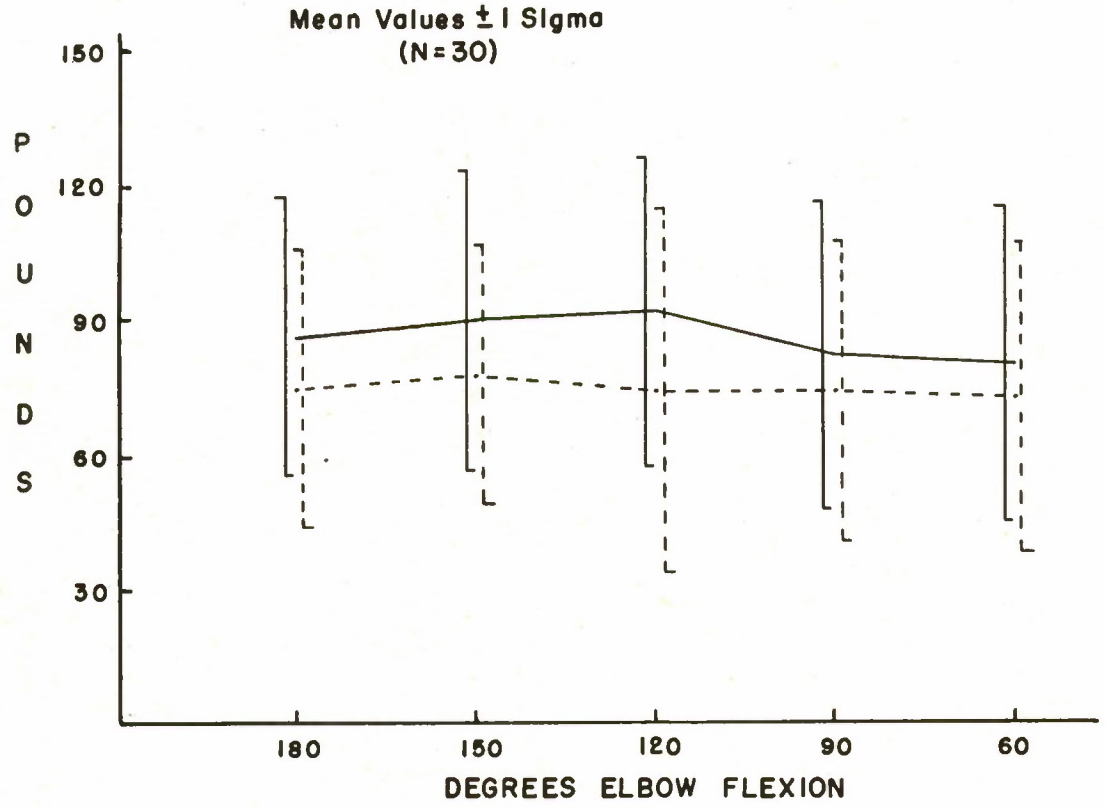



TABLE 5

POSITION OF WRIST: PRONATION
DIRECTION OF MOVEMENT: DOWN

| %-iles | Elbow Flexion | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Right Arm | | | | | Left Arm | | | | |
| | 180° | 150° | 120° | 90° | 60° | 180° | 150° | 120° | 90° | 60° |
| 5 | 41 | 40 | 37 | 22 | 23 | 34 | 39 | 29 | 23 | 18 |
| 10 | 43 | 47 | 58 | 37 | 47 | 36 | 43 | 35 | 30 | 26 |
| 20 | 52 | 58 | 65 | 55 | 53 | 45 | 48 | 42 | 48 | 46 |
| 30 | 59 | 69 | 70 | 65 | 61 | 51 | 56 | 53 | 65 | 60 |
| 40 | 77 | 75 | 78 | 75 | 67 | 63 | 68 | 64 | 67 | 66 |
| 50 | 87 | 81 | 83 | 79 | 70 | 69 | 76 | 72 | 73 | 71 |
| 60 | 93 | 93 | 90 | 90 | 79 | 77 | 79 | 78 | 82 | 76 |
| 70 | 97 | 101 | 95 | 94 | 91 | 85 | 91 | 82 | 86 | 84 |
| 80 | 107 | 111 | 108 | 97 | 105 | 97 | 104 | 92 | 89 | 91 |
| 90 | 136 | 140 | 146 | 127 | 115 | 114 | 112 | 122 | 93 | 106 |
| 95 | 143 | 154 | 161 | 142 | 158 | 138 | 136 | 148 | 136 | 139 |
| Low Score | 41 | 37 | 34 | 20 | 23 | 33 | 35 | 25 | 19 | 15 |
| High Score | 160 | 161 | 179 | 165 | 173 | 142 | 153 | 159 | 174 | 175 |
| Number | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 |
| Mean | 87 | 90 | 92 | 83 | 81 | 76 | 79 | 75 | 75 | 74 |
| Std. Dev. | 31 | 34 | 35 | 35 | 35 | 31 | 29 | 40 | 34 | 35 |

Wrists Pronated, Abduction (Table 6, Fig. 11)

It was quite difficult for the subjects to exert very much strength in this movement. The right arm scores ranged from a high mean value of 41 pounds at 60° to a low of 19 pounds at 180°. The plot for the left arm was quite similar with a high of 36 pounds at 60° and a low of 20 pounds at 180°. The low mean values were approximately 46 (right) and 56 (left) percent of the maximum values. The middle two-thirds of the distribution at 60° elbow flexion, ranged between 22 and 60 pounds for the right arm and between 21 and 51 pounds for the left arm.

Wrists Pronated, Adduction (Table 7, Fig. 12)

Although this action was somewhat stronger than abduction, it was one of the weaker movements. As in abduction, the strongest force was exerted with the elbows at 60°. Both the right arm and left arm forces increased as the elbow flexion changed from 180 to 60°. The scores, with the elbows at 60°, ranged from 15 to 84 pounds (right) and 17 to 72 pounds (left). The one sigma range for the right arm was 30 to 66 pounds and for the left arm 28 to 56 pounds. The minimum mean values were 63 and 67 percent of the maximum means.

Wrists Supinated, Forward Push (Table 8, Fig. 13)

The strength exerted in this movement varied considerably with the degrees of elbow flexion. At 180° the force was only 33 percent of the maximum at 60° flexion. The curves for both arms ran fairly parallel with increases in mean values as the elbow flexion ranged from 180 to 60°. Of the six movements done with the wrists supinated, this action yielded the second highest strength values. The scores ranged from 29 to 188 pounds with the right arm and from 26 to 195 pounds with the left arm. The middle two-thirds of the distribution varied between 57 and 135 pounds (right) and 47 to 131 pounds (left).

Wrists Supinated, Pull Back (Table 9, Fig. 14)

The degree of elbow flexion did not have a marked influence on the amount of strength that was possible in this action. In the case of the left arm the scores at 180, 150 and 120° were identical and 74 percent of the maximum, 54 pounds at 60°. The graph for the right arm was somewhat similar with a maximum at 60°. As in the Forward Push, the maximum was possible at the same degree of elbow flexion but the force was less than 60 percent of the value. The one sigma range from the mean extended from 27 to 75 pounds (right) and 31 to 77 pounds (left).

Fig. 11. POSITION OF WRIST: PRONATION
DIRECTION OF MOVEMENT: ABDUCTION

R. Hand ——
L. Hand ----

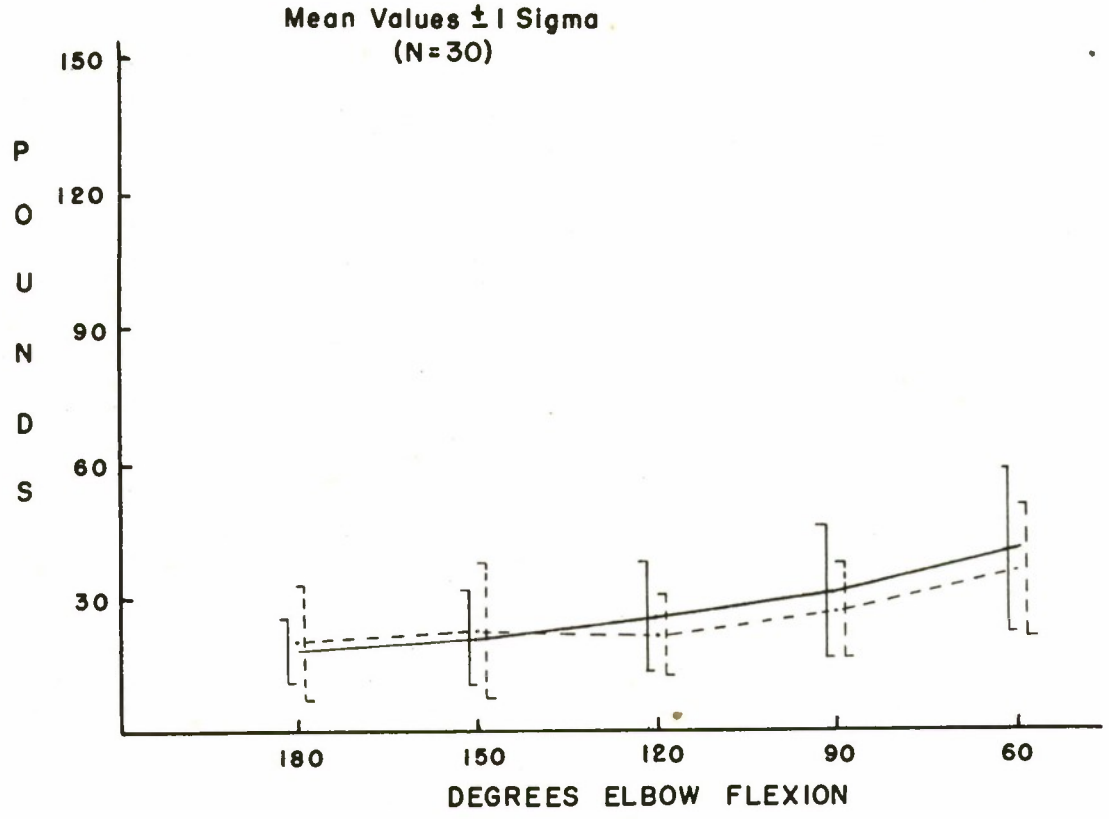



TABLE 6

POSITION OF WRIST: PRONATION
DIRECTION OF MOVEMENT: ABDUCTION

| %-iles | Elbow Flexion | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Right Arm | | | | | Left Arm | | | | |
| | 180° | 150° | 120° | 90° | 60° | 180° | 150° | 120° | 90° | 60° |
| 5 | 10 | 9 | 9 | 12 | 19 | 10 | 9 | 10 | 11 | 18 |
| 10 | 11 | 11 | 15 | 14 | 21 | 11 | 13 | 13 | 16 | 21 |
| 20 | 12 | 12 | 16 | 16 | 26 | 13 | 14 | 15 | 18 | 22 |
| 30 | 14 | 14 | 16 | 19 | 30 | 14 | 15 | 16 | 19 | 26 |
| 40 | 16 | 17 | 17 | 25 | 33 | 15 | 17 | 18 | 21 | 28 |
| 50 | 18 | 19 | 23 | 26 | 35 | 16 | 18 | 19 | 25 | 29 |
| 60 | 19 | 19 | 25 | 31 | 41 | 18 | 21 | 23 | 26 | 38 |
| 70 | 19 | 21 | 26 | 35 | 47 | 19 | 24 | 23 | 27 | 42 |
| 80 | 21 | 23 | 35 | 40 | 58 | 22 | 26 | 26 | 32 | 46 |
| 90 | 27 | 27 | 39 | 61 | 64 | 29 | 30 | 35 | 42 | 48 |
| 95 | 34 | 39 | 53 | 64 | 72 | 49 | 53 | 39 | 54 | 51 |
| Low Score | 9 | 8 | 7 | 11 | 18 | 8 | 8 | 7 | 8 | 15 |
| High Score | 44 | 71 | 67 | 67 | 87 | 64 | 83 | 46 | 58 | 100 |
| Number | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 |
| Mean | 19 | 21 | 26 | 31 | 41 | 20 | 23 | 22 | 27 | 36 |
| Std. Dev. | 7 | 11 | 13 | 15 | 19 | 13 | 16 | 10 | 11 | 15 |

Fig. 12. POSITION OF WRIST: PRONATION
DIRECTION OF MOVEMENT: ADDUCTION

R. Hand ——
L. Hand ----

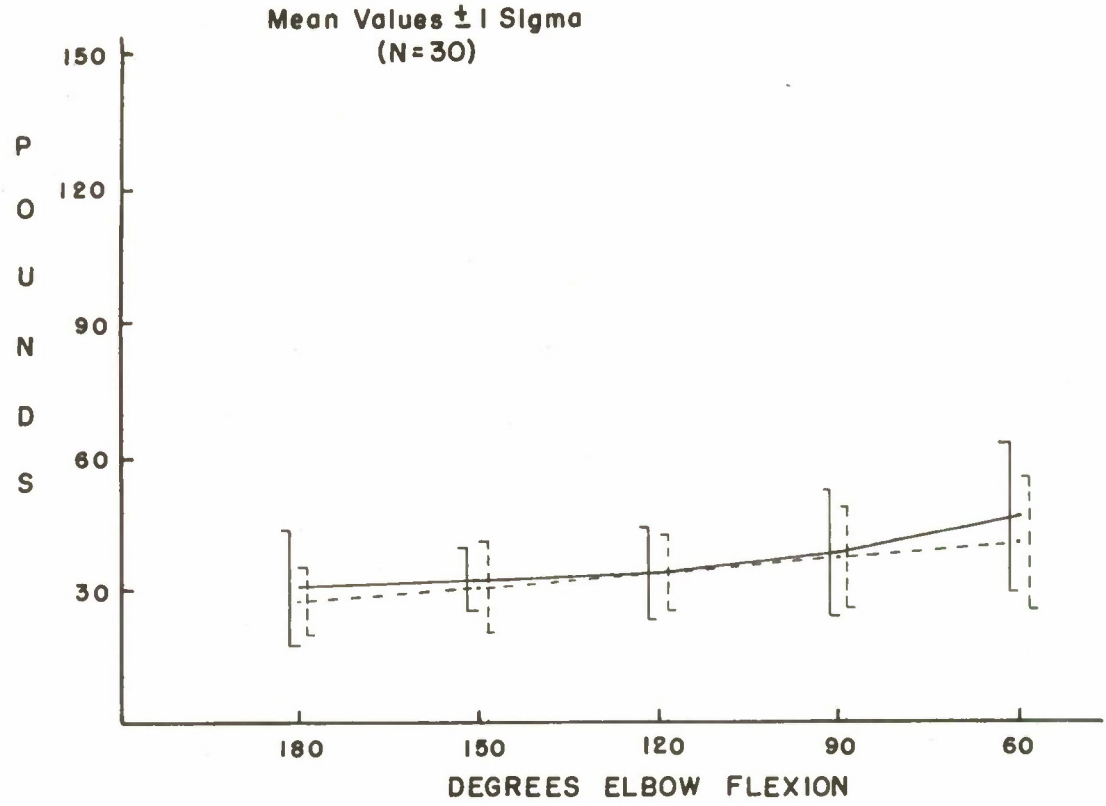



TABLE 7

POSITION OF WRIST: PRONATION
DIRECTION OF MOVEMENT: ADDUCTION

| %-iles | Elbow Flexion | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Right Arm | | | | | Left Arm | | | | |
| | 180° | 150° | 120° | 90° | 60° | 180° | 150° | 120° | 90° | 60° |
| 5 | 16 | 18 | 15 | 16 | 16 | 15 | 17 | 17 | 17 | 20 |
| 10 | 19 | 20 | 21 | 22 | 23 | 19 | 20 | 21 | 21 | 23 |
| 20 | 21 | 23 | 25 | 27 | 23 | 21 | 21 | 27 | 29 | 29 |
| 30 | 24 | 25 | 28 | 33 | 38 | 23 | 24 | 28 | 31 | 34 |
| 40 | 27 | 29 | 32 | 37 | 43 | 25 | 26 | 29 | 35 | 39 |
| 50 | 27 | 29 | 34 | 39 | 47 | 25 | 26 | 33 | 38 | 43 |
| 60 | 31 | 33 | 35 | 41 | 52 | 28 | 30 | 37 | 41 | 47 |
| 70 | 33 | 36 | 39 | 43 | 56 | 31 | 31 | 38 | 43 | 48 |
| 80 | 35 | 38 | 41 | 46 | 64 | 33 | 34 | 39 | 45 | 52 |
| 90 | 45 | 44 | 47 | 53 | 70 | 36 | 47 | 43 | 48 | 55 |
| 95 | 57 | 45 | 47 | 59 | 73 | 41 | 54 | 53 | 60 | 66 |
| Low Score | 12 | 15 | 16 | 15 | 15 | 14 | 15 | 16 | 16 | 17 |
| High Score | 58 | 56 | 59 | 83 | 84 | 55 | 70 | 55 | 67 | 72 |
| Number | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 |
| Mean | 31 | 32 | 34 | 39 | 48 | 28 | 31 | 34 | 38 | 42 |
| Std. Dev. | 13 | 7 | 11 | 15 | 18 | 8 | 11 | 8 | 12 | 15 |

Fig. 13. POSITION OF WRIST: SUPINATION
DIRECTION OF MOVEMENT: FORWARD

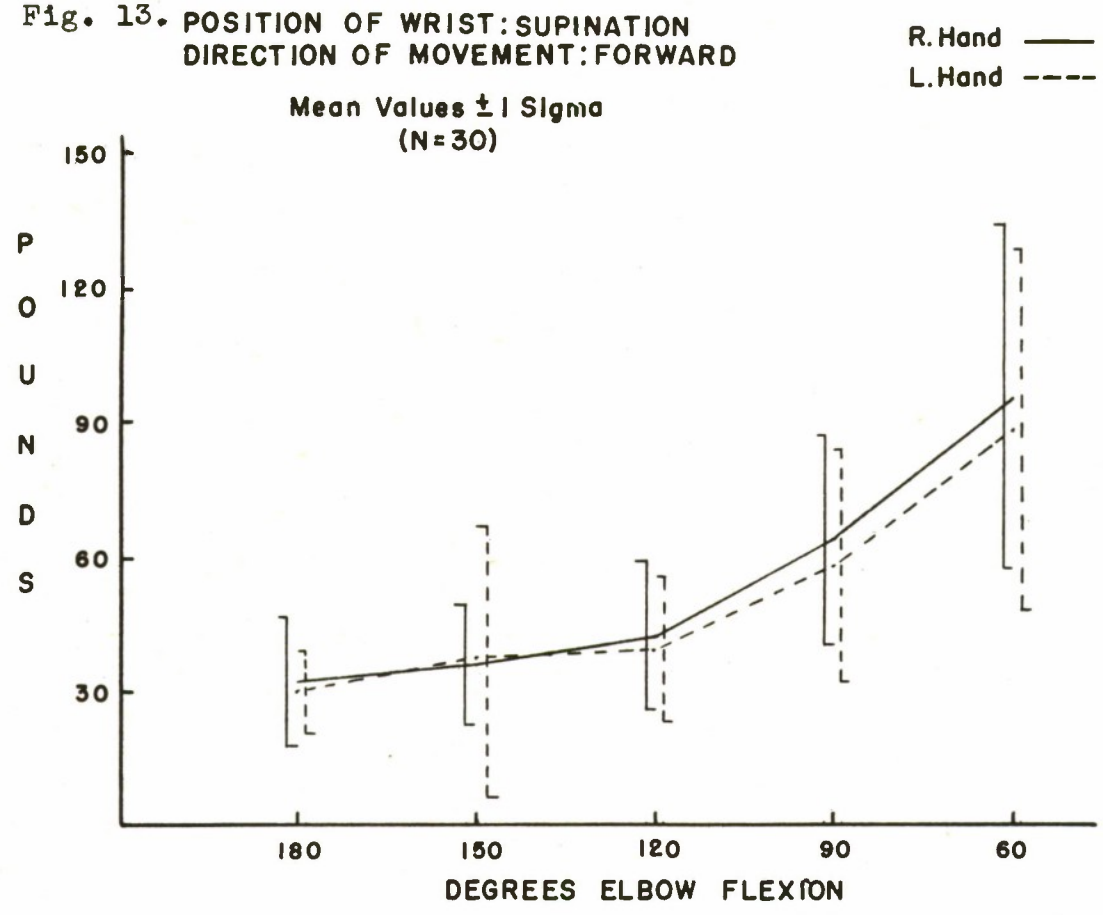



TABLE 8

POSITION OF WRIST: SUPINATION
DIRECTION OF MOVEMENT: FORWARD

| %-iles | Elbow Flexion | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Right Arm | | | | | Left Arm | | | | |
| | 180° | 150° | 120° | 90° | 60° | 180° | 150° | 120° | 90° | 60° |
| 5 | 12 | 17 | 20 | 25 | 34 | 14 | 13 | 15 | 25 | 35 |
| 10 | 17 | 21 | 25 | 31 | 53 | 18 | 13 | 19 | 31 | 48 |
| 20 | 20 | 26 | 28 | 43 | 67 | 19 | 22 | 27 | 36 | 55 |
| 30 | 24 | 28 | 35 | 53 | 74 | 23 | 29 | 28 | 42 | 64 |
| 40 | 29 | 29 | 38 | 55 | 79 | 26 | 31 | 32 | 50 | 72 |
| 50 | 30 | 33 | 41 | 59 | 86 | 30 | 32 | 35 | 55 | 77 |
| 60 | 31 | 38 | 44 | 62 | 104 | 33 | 36 | 40 | 59 | 89 |
| 70 | 34 | 39 | 48 | 74 | 109 | 34 | 40 | 44 | 65 | 92 |
| 80 | 39 | 45 | 56 | 78 | 122 | 36 | 42 | 50 | 73 | 113 |
| 90 | 55 | 56 | 64 | 94 | 141 | 38 | 58 | 59 | 89 | 160 |
| 95 | 58 | 59 | 71 | 117 | 172 | 47 | 69 | 80 | 104 | 176 |
| Low Score | 11 | 14 | 15 | 24 | 29 | 11 | 13 | 14 | 18 | 20 |
| High Score | 61 | 76 | 83 | 121 | 188 | 58 | 167 | 81 | 140 | 195 |
| Number | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 |
| Mean | 32 | 36 | 43 | 65 | 96 | 30 | 38 | 40 | 59 | 89 |
| Std. Dev. | 15 | 14 | 17 | 24 | 39 | 10 | 30 | 18 | 27 | 42 |

Fig. 14. POSITION OF WRIST: SUPINATION
DIRECTION OF MOVEMENT: BACK

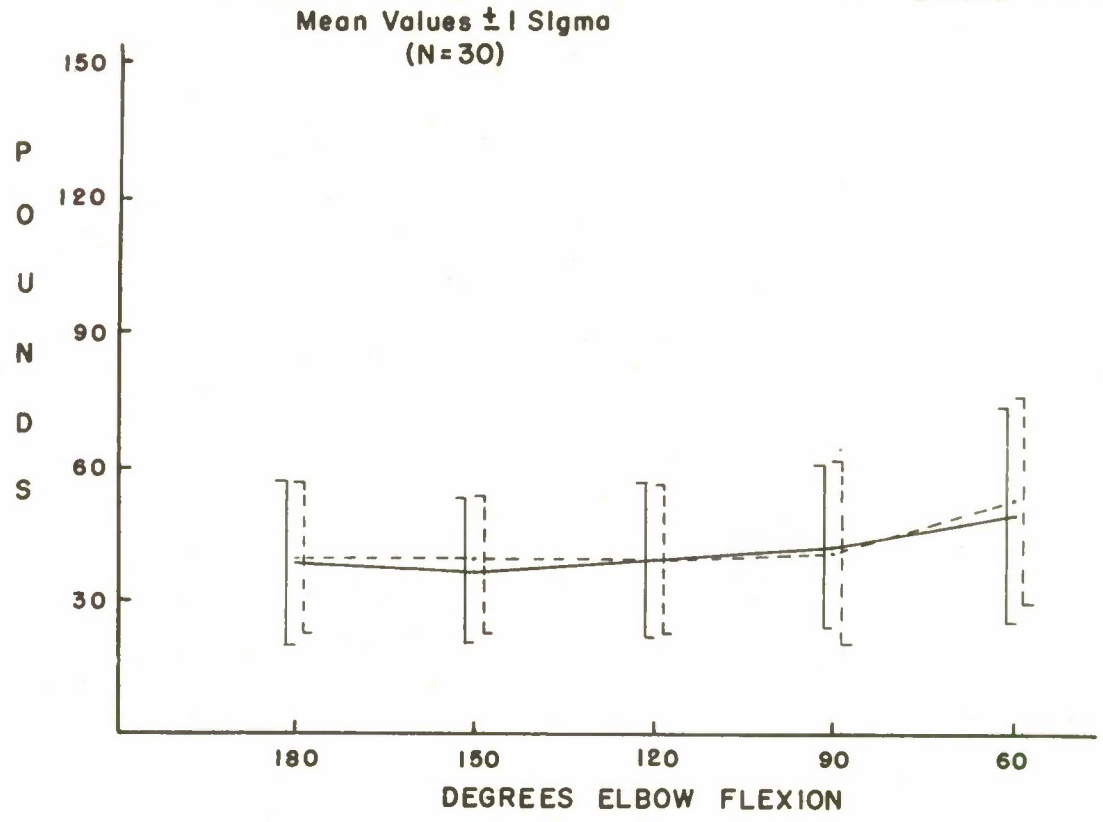



TABLE 9

POSITION OF WRIST: SUPINATION
DIRECTION OF MOVEMENT: BACK

| %-iles | Elbow Flexion | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Right Arm | | | | | Left Arm | | | | |
| | 180° | 150° | 120° | 90° | 60° | 180° | 150° | 120° | 90° | 60° |
| 5 | 15 | 11 | 11 | 13 | 16 | 17 | 16 | 14 | 13 | 23 |
| 10 | 17 | 15 | 16 | 19 | 23 | 19 | 22 | 18 | 15 | 28 |
| 20 | 22 | 21 | 22 | 22 | 27 | 22 | 24 | 22 | 21 | 31 |
| 30 | 26 | 27 | 28 | 30 | 34 | 28 | 27 | 26 | 27 | 36 |
| 40 | 30 | 28 | 36 | 31 | 37 | 35 | 31 | 34 | 34 | 48 |
| 50 | 36 | 34 | 39 | 41 | 49 | 38 | 39 | 38 | 42 | 53 |
| 60 | 40 | 40 | 46 | 43 | 54 | 40 | 43 | 43 | 47 | 56 |
| 70 | 43 | 44 | 51 | 52 | 64 | 45 | 46 | 48 | 50 | 61 |
| 80 | 56 | 53 | 57 | 54 | 66 | 51 | 52 | 56 | 56 | 71 |
| 90 | 65 | 57 | 61 | 66 | 72 | 63 | 61 | 58 | 61 | 83 |
| 95 | 73 | 66 | 63 | 74 | 93 | 70 | 62 | 66 | 68 | 87 |
| Low Score | 14 | 11 | 8 | 10 | 11 | 16 | 14 | 11 | 11 | 19 |
| High Score | 77 | 74 | 64 | 100 | 123 | 91 | 83 | 92 | 114 | 123 |
| Number | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 |
| Mean | 39 | 37 | 40 | 43 | 51 | 40 | 40 | 40 | 42 | 54 |
| Std. Dev. | 19 | 17 | 17 | 19 | 25 | 18 | 15 | 18 | 21 | 23 |

Wrists Supinated, Pull Up (Table 10, Fig. 15)

The greatest amount of strength could be exerted in this movement with the largest mean values for both arms when the elbows were extended to 180°. As the elbows were flexed to 150, 120, 90 and 60° the strength decreased. The two curves closely approximated each other. The weakest mean value for the right arm was 39 percent of the maximum and in the case of the left arm it was 44 percent. Once again there was a considerable range of scores and the middle two-thirds of the distribution scored between 79 and 147 pounds (right) and 71 to 151 (left).

Wrists Supinated, Push Down (Table 11, Fig. 16)

In pushing down the greatest strength was obtained when the elbows were at 150 or 120°. There was actually little difference between these two positions; one pound with the right arm and no difference with the left. The minimum force with the right arm at 60° was 64 percent of the maximum of 93 pounds at 150°. With the left arm the minimum of 58 pounds at 60° was 69 percent of the 84-pound maximum at 120 or 150°. The strongest subject was able to exert more than nine times as much strength as the weakest in this action. Once again the two curves ran fairly parallel with quite a drop-off between 90 and 60°.

Wrists Supinated, Abduction (Table 12, Fig. 17)

Abduction was one of the weaker movements of the six tested. In both the right and left arm actions the maximum strength was exerted with the elbows at 60°. The right arm strength increased as the elbow flexion changed from 180° through the five positions to 60°. In the case of the left arm the scores were approximately the same at the first three positions and then increased some at 90 and 60°. The one sigma range extended from 25 to 63 pounds (right) and from 23 to 61 pounds (left). The lowest score was approximately one-fifth the highest.

Wrists Supinated, Adduction (Table 13, Fig. 18)

Once again it was difficult to exert much strength in this movement. In fact, the action was the weakest of the six tested. The highest mean values, at 60° flexion, were only 36 and 38 pounds for the right and left arms. The two curves ran practically together from the 180° plot to the 60° plot. The middle two-thirds of the scores ranged from 19 to 53 pounds (right) and from 26 to 50 pounds (left). The strongest subject in this action was able to exert over seven times as much force as the weakest. The degrees of elbow flexion did not influence these scores appreciably.

Fig. 15.

POSITION OF WRIST: SUPINATION
DIRECTION OF MOVEMENT: UP

R. Hand ——
L. Hand ----

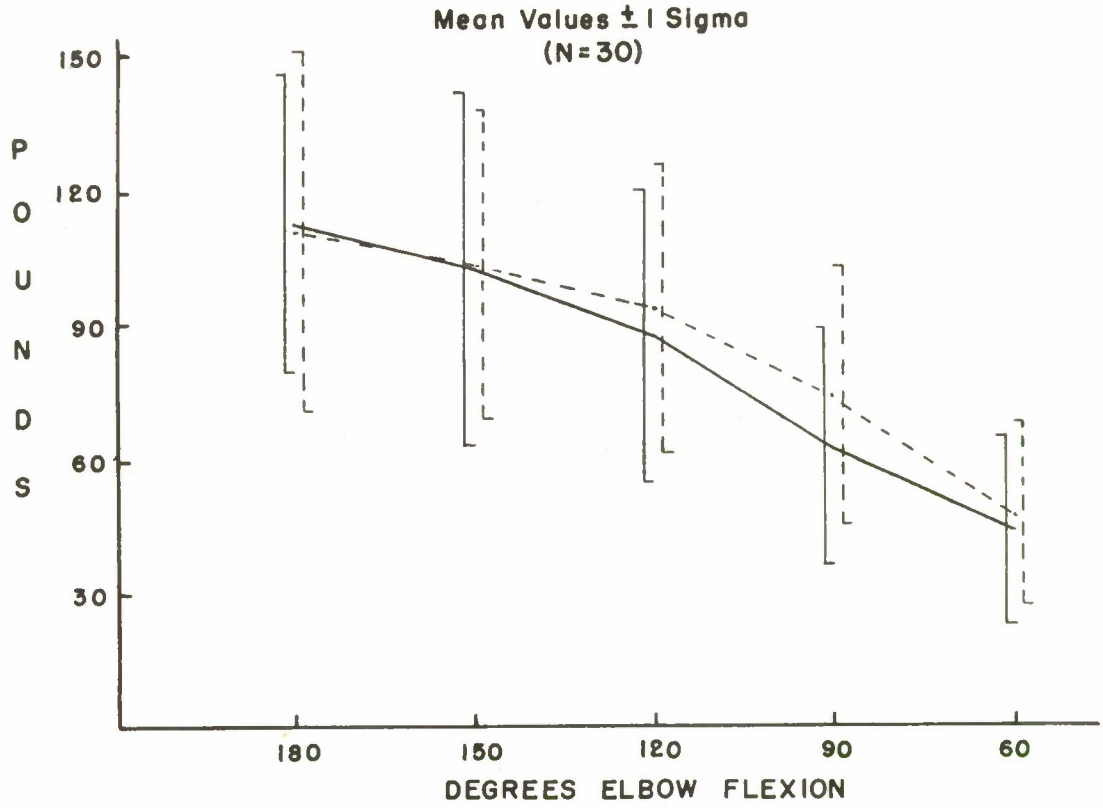



TABLE 10

POSITION OF WRIST: SUPINATION
DIRECTION OF MOVEMENT: UP

| %-iles | Elbow Flexion | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Right Arm | | | | | Left Arm | | | | |
| | 180° | 150° | 120° | 90° | 60° | 180° | 150° | 120° | 90° | 60° |
| 5 | 51 | 37 | 41 | 21 | 17 | 45 | 44 | 38 | 24 | 20 |
| 10 | 66 | 42 | 41 | 29 | 20 | 60 | 58 | 45 | 30 | 27 |
| 20 | 78 | 62 | 59 | 31 | 26 | 69 | 68 | 69 | 51 | 32 |
| 30 | 87 | 79 | 73 | 49 | 31 | 77 | 74 | 80 | 55 | 35 |
| 40 | 98 | 94 | 80 | 58 | 35 | 91 | 89 | 86 | 63 | 40 |
| 50 | 119 | 108 | 84 | 64 | 42 | 102 | 101 | 94 | 77 | 43 |
| 60 | 123 | 115 | 93 | 69 | 47 | 135 | 117 | 100 | 82 | 47 |
| 70 | 135 | 125 | 103 | 76 | 50 | 139 | 126 | 105 | 86 | 58 |
| 80 | 143 | 134 | 109 | 83 | 60 | 144 | 138 | 111 | 88 | 66 |
| 90 | 147 | 139 | 118 | 90 | 68 | 171 | 143 | 124 | 95 | 82 |
| 95 | 165 | 161 | 143 | 107 | 78 | 173 | 164 | 152 | 131 | 89 |
| Low Score | 41 | 36 | 40 | 18 | 16 | 40 | 42 | 34 | 23 | 17 |
| High Score | 185 | 188 | 164 | 123 | 112 | 175 | 175 | 176 | 151 | 93 |
| Number | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 |
| Mean | 113 | 103 | 88 | 63 | 45 | 111 | 104 | 94 | 75 | 49 |
| Std. Dev. | 34 | 40 | 33 | 27 | 22 | 40 | 36 | 33 | 29 | 22 |

Fig. 16. POSITION OF WRIST: SUPINATION
DIRECTION OF MOVEMENT: DOWN

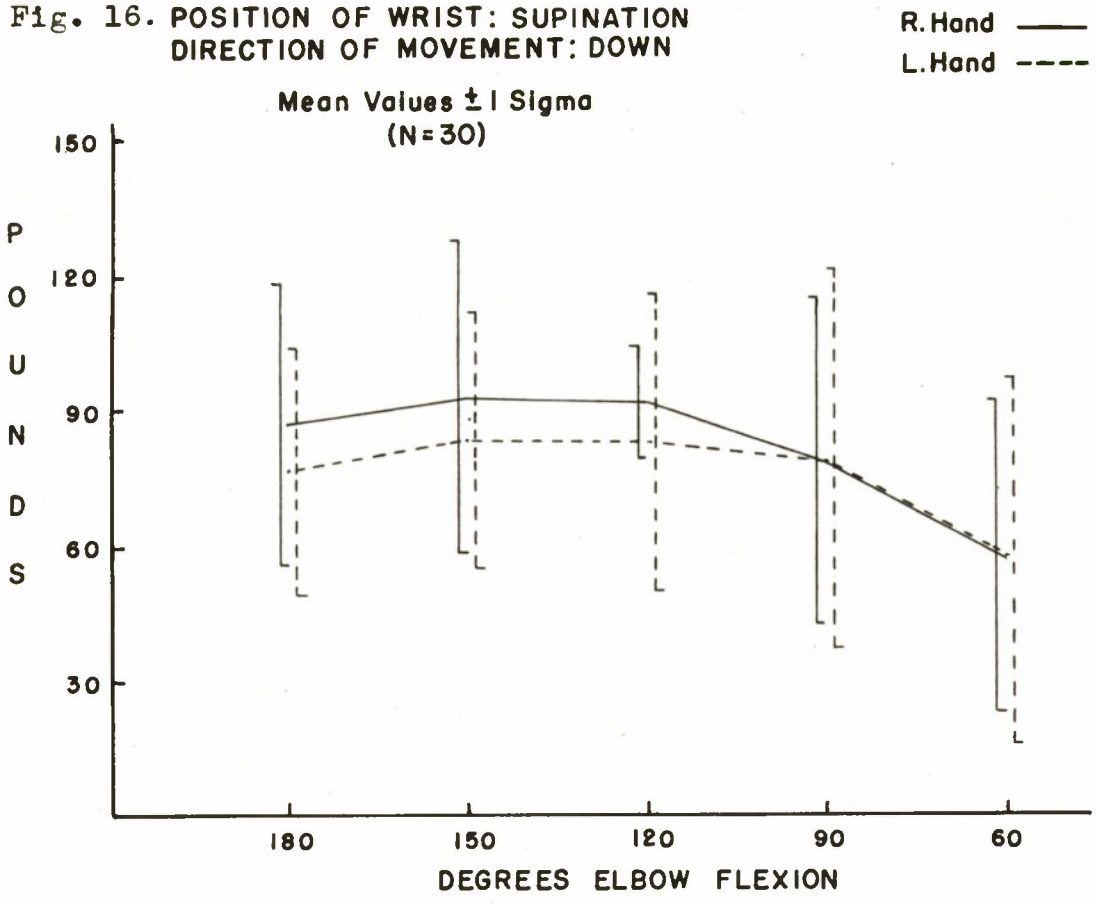



TABLE 11

POSITION OF WRIST: SUPINATION
DIRECTION OF MOVEMENT: DOWN

| %-iles | Elbow Flexion | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Right Arm | | | | | Left Arm | | | | |
| | 180° | 150° | 120° | 90° | 60° | 180° | 150° | 120° | 90° | 60° |
| 5 | 44 | 37 | 29 | 17 | 20 | 36 | 43 | 35 | 23 | 20 |
| 10 | 52 | 43 | 45 | 24 | 22 | 40 | 48 | 41 | 24 | 21 |
| 20 | 59 | 55 | 61 | 46 | 28 | 54 | 57 | 49 | 37 | 25 |
| 30 | 62 | 69 | 71 | 56 | 37 | 58 | 67 | 64 | 55 | 33 |
| 40 | 69 | 80 | 72 | 67 | 43 | 75 | 74 | 71 | 64 | 36 |
| 50 | 83 | 83 | 91 | 74 | 51 | 77 | 78 | 77 | 78 | 39 |
| 60 | 89 | 101 | 103 | 81 | 59 | 80 | 82 | 90 | 85 | 53 |
| 70 | 102 | 113 | 105 | 93 | 65 | 82 | 90 | 95 | 95 | 70 |
| 80 | 111 | 128 | 130 | 106 | 74 | 92 | 99 | 110 | 112 | 78 |
| 90 | 123 | 136 | 137 | 129 | 86 | 112 | 114 | 121 | 122 | 101 |
| 95 | 135 | 150 | 148 | 143 | 132 | 124 | 136 | 136 | 160 | 138 |
| Low Score | 41 | 34 | 27 | 15 | 19 | 34 | 38 | 30 | 23 | 20 |
| High Score | 179 | 178 | 173 | 166 | 172 | 172 | 174 | 175 | 181 | 189 |
| Number | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 |
| Mean | 87 | 93 | 92 | 80 | 59 | 78 | 84 | 84 | 80 | 58 |
| Std. Dev. | 32 | 35 | 13 | 37 | 35 | 28 | 29 | 33 | 43 | 41 |

Fig. 17. POSITION OF WRIST: SUPINATION
DIRECTION OF MOVEMENT: ABDUCTION

R. Hand ——
L. Hand ----

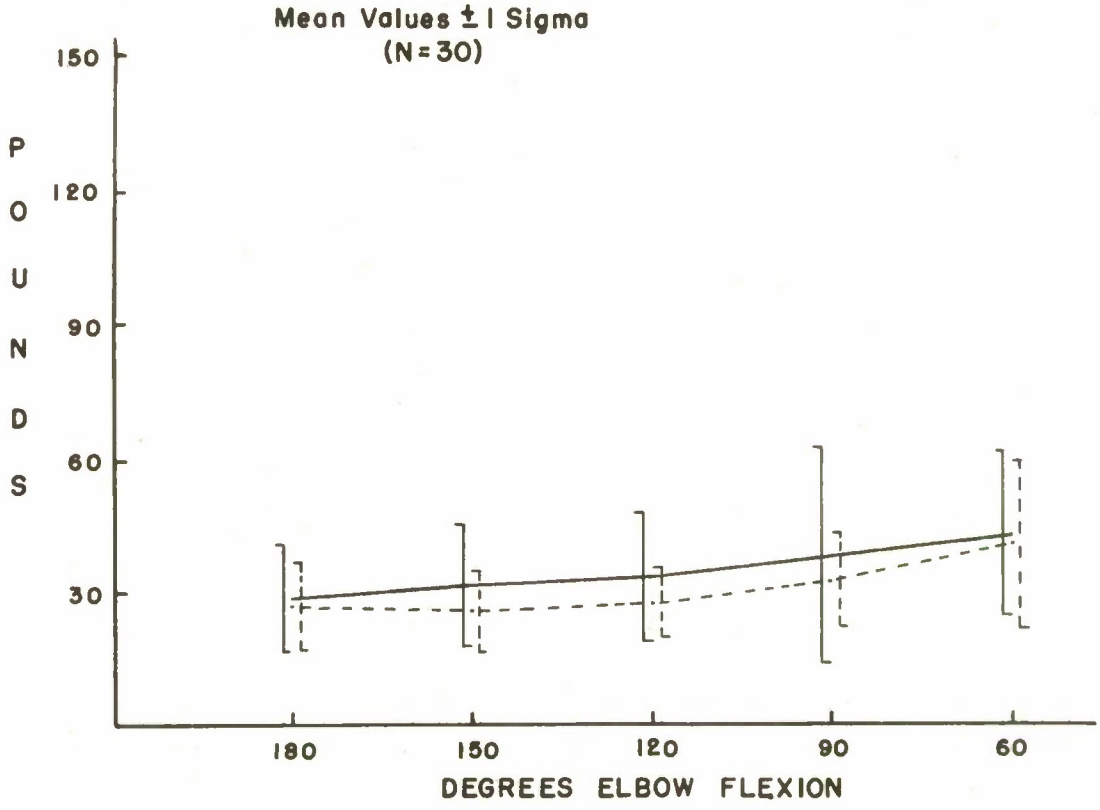



TABLE 12

POSITION OF WRIST: SUPINATION
DIRECTION OF MOVEMENT: ABDUCTION

| %-iles | Elbow Flexion | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Right Arm | | | | | Left Arm | | | | |
| | 180° | 150° | 120° | 90° | 60° | 180° | 150° | 120° | 90° | 60° |
| 5 | 14 | 15 | 17 | 18 | 18 | 8 | 12 | 14 | 16 | 17 |
| 10 | 18 | 19 | 18 | 18 | 19 | 12 | 15 | 15 | 17 | 22 |
| 20 | 19 | 23 | 20 | 27 | 27 | 18 | 18 | 19 | 21 | 25 |
| 30 | 22 | 25 | 25 | 31 | 31 | 23 | 22 | 21 | 25 | 29 |
| 40 | 25 | 27 | 28 | 34 | 34 | 25 | 26 | 25 | 28 | 30 |
| 50 | 26 | 28 | 31 | 35 | 40 | 26 | 26 | 27 | 30 | 34 |
| 60 | 30 | 28 | 36 | 38 | 44 | 28 | 26 | 29 | 34 | 39 |
| 70 | 32 | 30 | 38 | 44 | 49 | 30 | 28 | 30 | 36 | 45 |
| 80 | 39 | 37 | 41 | 46 | 58 | 32 | 31 | 35 | 41 | 57 |
| 90 | 41 | 47 | 51 | 63 | 69 | 37 | 36 | 41 | 49 | 74 |
| 95 | 48 | 60 | 64 | 72 | 73 | 44 | 43 | 45 | 52 | 81 |
| Low Score | 12 | 14 | 16 | 17 | 18 | 6 | 10 | 13 | 16 | 16 |
| High Score | 67 | 80 | 76 | 77 | 94 | 52 | 47 | 45 | 70 | 93 |
| Number | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 |
| Mean | 29 | 32 | 34 | 39 | 44 | 27 | 26 | 28 | 33 | 42 |
| Std. Dev. | 12 | 14 | 15 | 24 | 19 | 10 | 10 | 8 | 12 | 20 |

Fig. 18. POSITION OF WRIST: SUPINATION
DIRECTION OF MOVEMENT: ADDUCTION

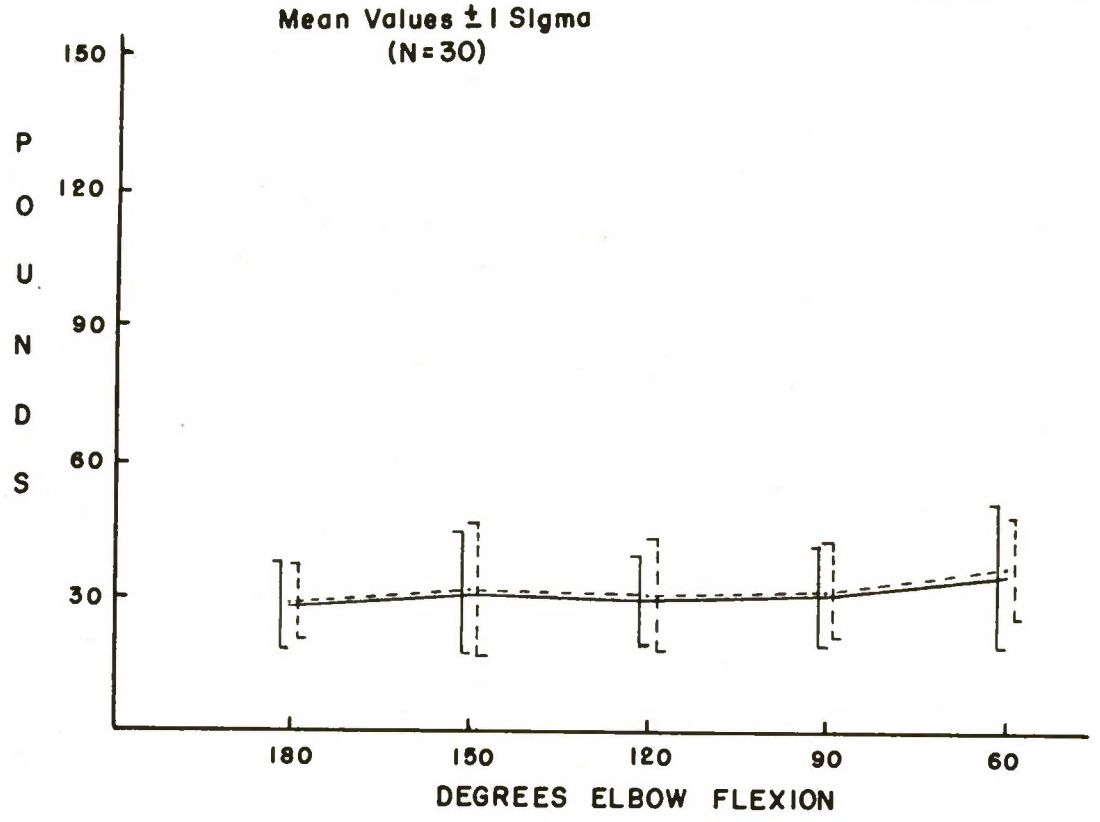



TABLE 13

POSITION OF WRIST: SUPINATION
DIRECTION OF MOVEMENT: ADDUCTION

| %-iles | Elbow Flexion | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Right Arm | | | | | Left Arm | | | | |
| | 180° | 150° | 120° | 90° | 60° | 180° | 150° | 120° | 90° | 60° |
| 5 | 10 | 12 | 12 | 13 | 13 | 12 | 12 | 14 | 12 | 16 |
| 10 | 17 | 13 | 21 | 16 | 18 | 14 | 13 | 16 | 15 | 22 |
| 20 | 19 | 22 | 22 | 22 | 24 | 17 | 20 | 22 | 22 | 23 |
| 30 | 21 | 24 | 23 | 26 | 28 | 21 | 23 | 22 | 25 | 30 |
| 40 | 25 | 25 | 25 | 28 | 31 | 26 | 26 | 26 | 28 | 32 |
| 50 | 29 | 30 | 28 | 28 | 34 | 28 | 30 | 28 | 31 | 34 |
| 60 | 29 | 32 | 33 | 33 | 36 | 31 | 35 | 33 | 34 | 36 |
| 70 | 32 | 36 | 35 | 36 | 38 | 34 | 37 | 35 | 38 | 41 |
| 80 | 37 | 37 | 39 | 37 | 41 | 36 | 39 | 40 | 38 | 47 |
| 90 | 42 | 47 | 45 | 42 | 43 | 42 | 49 | 44 | 44 | 54 |
| 95 | 44 | 52 | 46 | 48 | 70 | 43 | 62 | 55 | 46 | 64 |
| Low Score | 9 | 12 | 10 | 11 | 12 | 10 | 11 | 12 | 8 | 12 |
| High Score | 49 | 78 | 50 | 70 | 93 | 58 | 68 | 61 | 70 | 69 |
| Number | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 |
| Mean | 28 | 31 | 30 | 31 | 36 | 29 | 32 | 31 | 32 | 38 |
| Std. Dev. | 10 | 14 | 11 | 12 | 17 | 9 | 15 | 13 | 12 | 12 |

SECTION IV

## WRIST PRONATION AND SUPINATION STRENGTH

After completing the first phase of the research it was decided to test the amount of strength young men could exert during wrist pronation and wrist supination. These movements seemed important because they are called for in numerous manually-operated control systems. Since some of the subjects used in the other strength tests were no longer available a new sample had to be drawn. Once again it seemed important the same regard be given for the physical characteristics of the sample. A total of 25 subjects were selected based on the anthropometric measurements given in the Hertzberg, Daniels and Churchill report (6). The subjects were all students at the University of Michigan and like the previous sample were paid for their services.

Fig. 19. Wrist Pronation-Supination



3

The actual tests were carried out on a Kellogg Universal Dynamometer. This is part of the laboratory equipment in the Physical Education Research Laboratory at the University. The dynamometer operates on the principle of a piston displacing mercury. It is more fully described in an article by Hunsicker and Donnelly (8). Each subject was asked to sit erect, with both feet on the floor, elbows at a right angle and hand grasping the handle of the dynamometer (Fig. 19).

With the testee in the correct position, the four strength tests were given in this order:

1. Pronation, right hand.
2. Supination, left hand.
3. Pronation, left hand.
4. Supination, right hand.

The subject was asked to put forth a maximum effort in each instance and this was recorded. Since the dynamometer is equipped with a maximum stop hand which holds until reset by the operator this presented no problem.

TABLE 14

WRIST PRONATION AND SUPINATION STRENGTH

| %-iles | Pronation | | Supination | |
|---|---|---|---|---|
| | Right | Left | Right | Left |
| 5 | 29 | 31 | 35 | 30 |
| 10 | 38 | 35 | 41 | 38 |
| 20 | 43 | 45 | 48 | 42 |
| 30 | 45 | 48 | 52 | 47 |
| 40 | 57 | 56 | 55 | 59 |
| 50 | 67 | 63 | 59 | 62 |
| 60 | 73 | 69 | 66 | 65 |
| 70 | 82 | 88 | 74 | 71 |
| 80 | 98 | 99 | 80 | 78 |
| 90 | 113 | 111 | 83 | 82 |
| 95 | 119 | 132 | 93 | 88 |
| Low Score | 27 | 29 | 33 | 28 |
| High Score | 120 | 140 | 107 | 97 |
| Number | 25 | 25 | 25 | 25 |
| Mean | 71 | 71 | 64 | 62 |
| Std. Dev. | 28 | 31 | 18 | 16 |

An examination of the results of these tests (Table 14) indicates that a moderately high amount of strength was possible in pronation and supination. The average strength in pronation was 71 pounds (right) with two-thirds of the distribution between 43 and 99 pounds, and with the left hand the mean was the same and the one sigma range extended from 40 to 102 pounds. There was very little difference between the strength of the right hand as compared to the left. The difference between the low and high scores were not as marked in this action as they were in most of the other strength tests.

## SECTION V

## STRENGTH DECREMENT WITH LOSS OF SLEEP

The third phase of the testing program involved administering strength tests to selected subjects whose sleep had been restricted. A cue was taken from the routine which the aircrew members followed during the B-52 flight around the world. It was decided to allow the testees a total of four hours sleep in a 48-hour period.

Because of the nature of the restrictions placed on the subjects and because of expenses involved the sample was limited to six subjects. Here again an effort was made to span the range of physical characteristics of aircrew members. Two of the subjects were below the average in size; two were about average; and the other two were above average with one of these toward the upper end of the distribution.

The subjects were asked to adhere to the following schedule for the test period:

1. Rise at approximately 7 AM, Saturday.
2. Report to the laboratory at noon Saturday.
3. Briefing regarding test procedure and design of research. Opportunity to familiarize subjects with test apparatus and chance for trial runs.
4. First test trials at approximately 2 PM, Saturday.
5. Tests approximately every hour thereafter until 7 AM, Monday (total of 42 trials).
6. Subjects confined to laboratory and adjacent area except for two meals on Saturday and Sunday evenings.
7. Subjects had coffee, fruit, milk, cookies, etc., at their disposal in the laboratory.
8. Subjects were permitted a total of four hours sleep in the laboratory. Five took advantage of this but Subject T did not sleep during the entire period.
9. Subjects were permitted to read, study, listen to the radio, play cards or talk.

## Description of Tests

The subject was seated to the left of the Kellogg Dynamometer and the dynamometer handle was adjusted so he could grasp it with the right arm fully extended (Fig. 20). On one trial the wrist was pronated and on the second it was supinated. On the signal "Go" the testee lifted up as hard as he could. The maximum reading was recorded. After finishing the two tests with the right arm the subject moved to a chair that was fixed to the floor on the right of the dynamometer and repeated the two tests with the left arm.

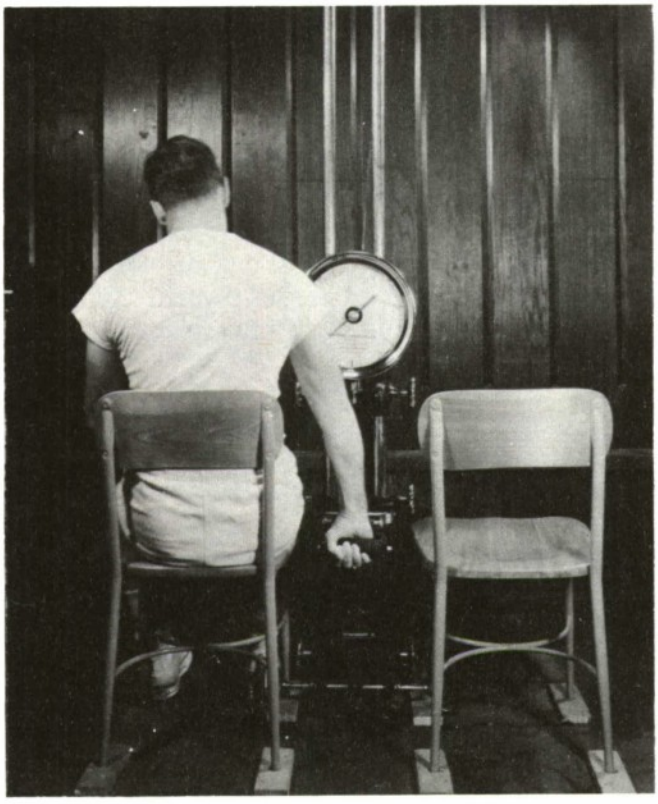


Fig. 20. Strength-Decrement Test Position

## Test Results

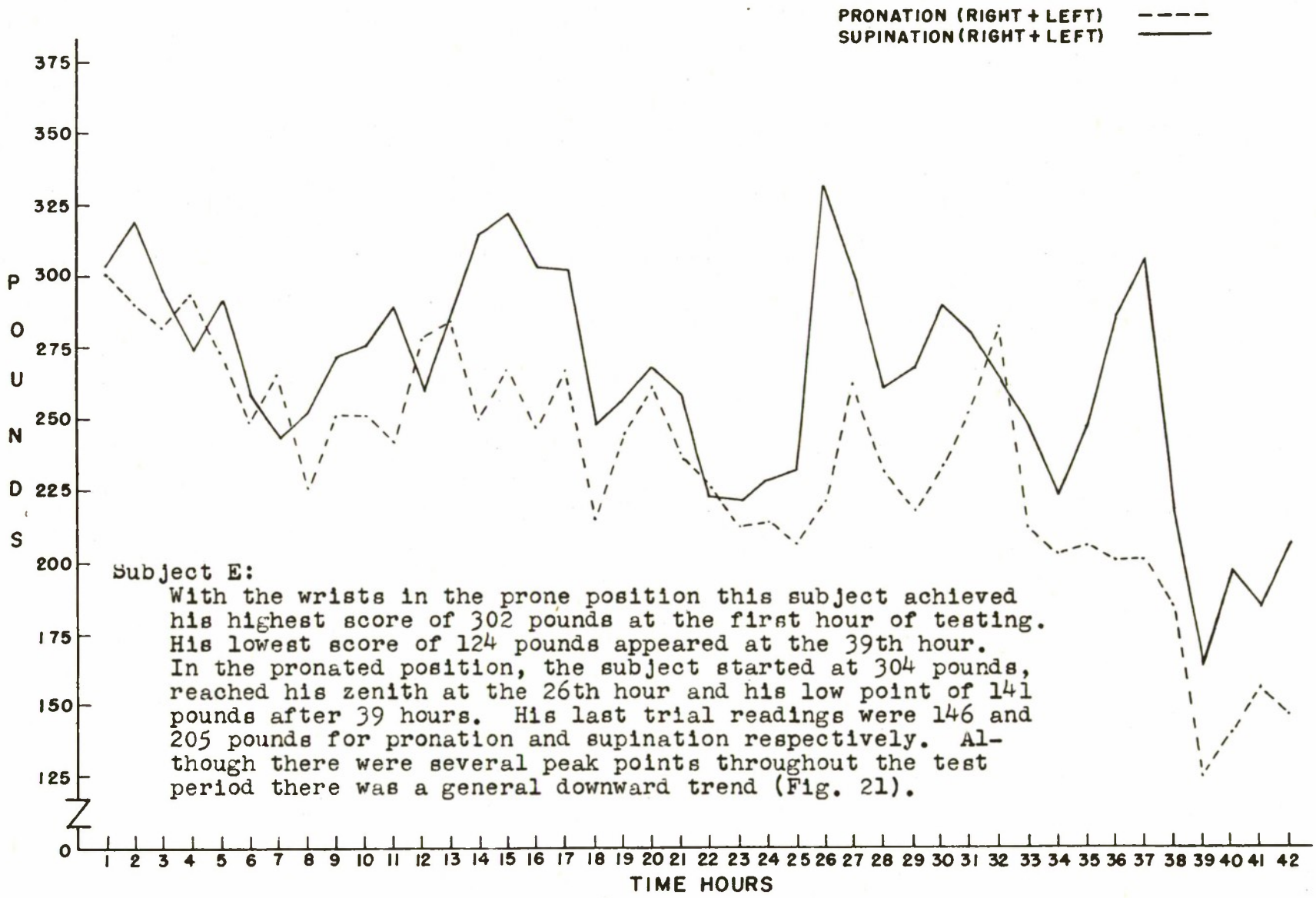
Since only six subjects were tested in this phase of the research it seems wise to discuss the results as individual cases. In analyzing the data from the standpoint of strength decrement, both the right and left arm scores were summated to give a single score for pronation and one for supination. These are the strength readings which appear in Table 15 and form the bases for Figures 21-26.

TABLE 15

STRENGTH DECREMENT WITH LOSS OF SLEEP

| | Subject | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | E | | H | | L | | P | | S | | T | |
| Hours | Pron. | Sup. | Pron. | Sup. | Pron. | Sup. | Pron. | Sup. | Pron. | Sup. | Pron. | Sup. |
| 1 | 302 | 304 | 239 | 235 | 256 | 319 | 233 | 287 | 172 | 218 | 248 | 265 |
| 2 | 280 | 329 | 243 | 238 | 278 | 288 | 273 | 277 | 196 | 232 | 286 | 313 |
| 3 | 281 | 296 | 214 | 221 | 290 | 300 | 244 | 298 | 205 | 199 | 271 | 322 |
| 4 | 294 | 274 | 228 | 264 | 278 | 304 | 253 | 318 | 165 | 178 | 281 | 317 |
| 5 | 273 | 291 | 247 | 257 | 291 | 302 | 284 | 342 | 157 | 201 | 272 | 311 |
| 6 | 248 | 258 | 253 | 238 | 288 | 315 | 273 | 323 | 172 | 211 | 265 | 289 |
| 7 | 265 | 243 | 254 | 248 | 276 | 298 | 260 | 291 | 167 | 244 | 275 | 303 |
| 8 | 225 | 252 | 239 | 251 | 243 | 344 | 271 | 324 | 196 | 243 | 278 | 320 |
| 9 | 251 | 271 | 233 | 220 | 309 | 320 | 284 | 304 | 201 | 220 | 253 | 305 |
| 10 | 250 | 275 | 233 | 228 | 311 | 309 | 288 | 305 | 179 | 221 | 266 | 287 |
| 11 | 242 | 289 | 233 | 229 | 279 | 345 | 262 | 284 | 183 | 215 | 244 | 296 |
| 12 | 278 | 260 | 239 | 233 | 309 | 322 | 258 | 297 | 175 | 214 | 246 | 305 |
| 13 | 284 | 282 | 202 | 222 | 253 | 312 | 260 | 303 | 188 | 197 | 264 | 314 |
| 14 | 260 | 311 | 218 | 261 | 315 | 321 | 250 | 336 | 174 | 241 | 272 | 344 |
| 15 | 267 | 323 | 201 | 202 | 306 | 381 | 285 | 343 | 191 | 209 | 264 | 337 |
| 16 | 246 | 303 | 227 | 213 | 342 | 350 | 284 | 341 | 198 | 206 | 276 | 323 |
| 17 | 268 | 301 | 219 | 212 | 342 | 373 | 270 | 361 | 195 | 200 | 279 | 323 |
| 18 | 215 | 246 | 220 | 240 | 292 | 313 | 255 | 351 | 197 | 208 | 244 | 294 |
| 19 | 244 | 256 | 220 | 269 | 234 | 315 | 259 | 347 | 196 | 208 | 246 | 302 |
| 20 | 261 | 268 | 211 | 217 | 324 | 393 | 273 | 349 | 198 | 209 | 259 | 309 |
| 21 | 238 | 257 | 206 | 226 | 338 | 368 | 233 | 342 | 219 | 209 | 241 | 290 |
| 22 | 226 | 224 | 228 | 215 | 333 | 360 | 275 | 351 | 215 | 210 | 253 | 294 |
| 23 | 212 | 220 | 216 | 228 | 294 | 336 | 257 | 318 | 186 | 214 | 248 | 302 |
| 24 | 213 | 228 | 202 | 202 | 264 | 312 | 328 | 307 | 189 | 221 | 245 | 309 |
| 25 | 205 | 231 | 189 | 219 | 275 | 378 | 250 | 347 | 196 | 256 | 251 | 307 |
| 26 | 220 | 331 | 235 | 222 | 302 | 317 | 262 | 339 | 195 | 220 | 237 | 298 |
| 27 | 262 | 299 | 207 | 240 | 234 | 277 | 247 | 325 | 196 | 221 | 244 | 324 |
| 28 | 230 | 260 | 227 | 225 | 220 | 207 | 235 | 329 | 204 | 283 | 248 | 326 |
| 29 | 217 | 266 | 208 | 245 | 246 | 251 | 268 | 348 | 188 | 228 | 244 | 313 |
| 30 | 233 | 289 | 202 | 203 | 248 | 315 | 250 | 345 | 195 | 183 | 248 | 318 |
| 31 | 252 | 280 | 222 | 244 | 247 | 354 | 213 | 312 | 202 | 244 | 238 | 305 |
| 32 | 281 | 262 | 207 | 208 | 250 | 328 | 248 | 274 | 209 | 230 | 243 | 297 |
| 33 | 212 | 247 | 209 | 216 | 314 | 329 | 247 | 282 | 181 | 233 | 224 | 321 |
| 34 | 202 | 223 | 156 | 178 | 291 | 335 | 224 | 288 | 201 | 263 | 241 | 291 |
| 35 | 205 | 247 | 142 | 135 | 252 | 271 | 233 | 277 | 175 | 211 | 229 | 297 |
| 36 | 199 | 285 | 127 | 165 | 219 | 279 | 189 | 276 | 200 | 230 | 220 | 310 |
| 37 | 203 | 305 | 185 | 201 | 240 | 287 | 239 | 317 | 204 | 233 | 239 | 289 |
| 38 | 184 | 217 | 180 | 177 | 262 | 266 | 198 | 273 | 204 | 210 | 247 | 279 |
| 39 | 124 | 141 | 170 | 182 | 164 | 212 | 224 | 275 | 192 | 244 | 225 | 261 |
| 40 | 140 | 196 | 156 | 203 | 149 | 251 | 233 | 284 | 173 | 215 | 225 | 283 |
| 41 | 156 | 184 | 181 | 205 | 166 | 239 | 194 | 227 | 171 | 210 | 222 | 294 |
| 42 | 146 | 205 | 188 | 232 | 190 | 199 | 228 | 298 | 200 | 260 | 237 | 299 |

Fig. 21
STRENGTH DECREMENT
WITH FATIGUE
(SUBJECT E )




Subject E:
With the wrists in the prone position this subject achieved his highest score of 302 pounds at the first hour of testing. His lowest score of 124 pounds appeared at the 39th hour. In the pronated position, the subject started at 304 pounds, reached his zenith at the 26th hour and his low point of 141 pounds after 39 hours. His last trial readings were 146 and 205 pounds for pronation and supination respectively. Although there were several peak points throughout the test period there was a general downward trend (Fig. 21).

Fig. 22

STRENGTH DECREMENT
WITH FATIGUE
(SUBJECT H )

Subject H:
The testee started at 239 pounds for the pronated position and 235 pounds for supination. His greatest strength effort appeared at the 7th hour (pronation) and the 19th hour (supination). His lowest scores were 127 and 135 pounds and came at the 36th and 35th hours respectively. These were about 50 percent of his maximum lifts. His final scores were 188 (pronation) and 232 (supination). His weakest period was between the 33rd and 40th hours (Fig. 22).

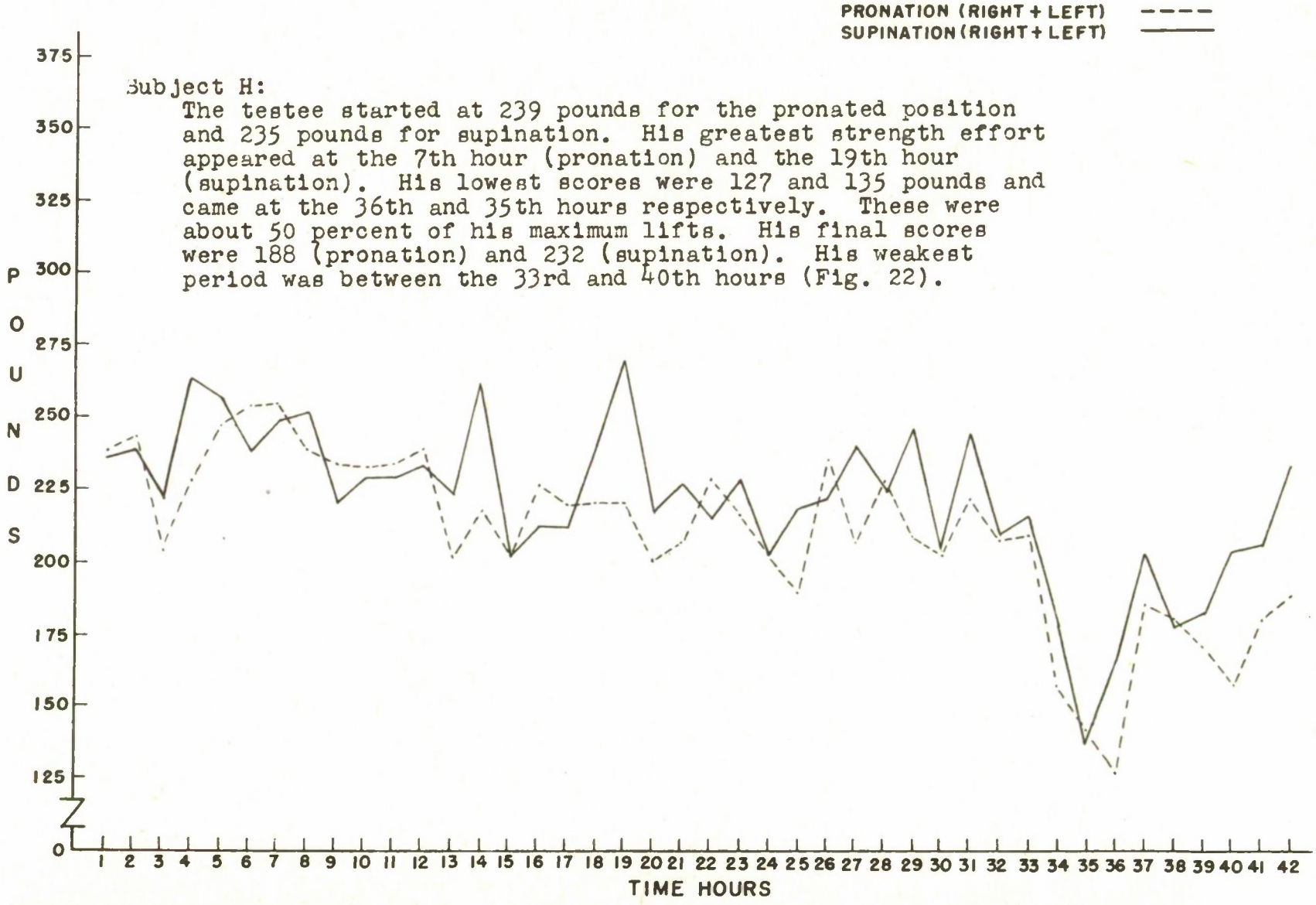
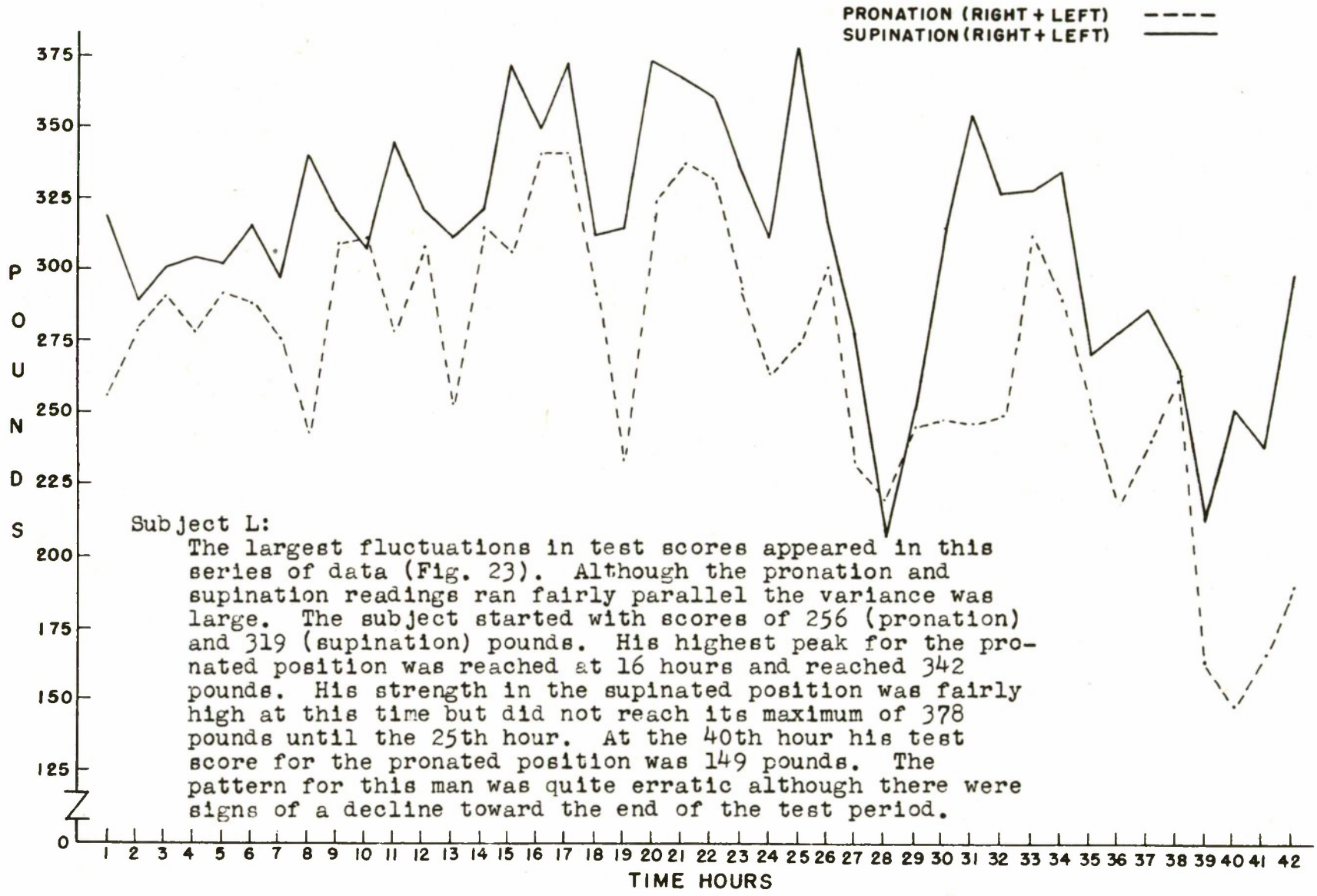
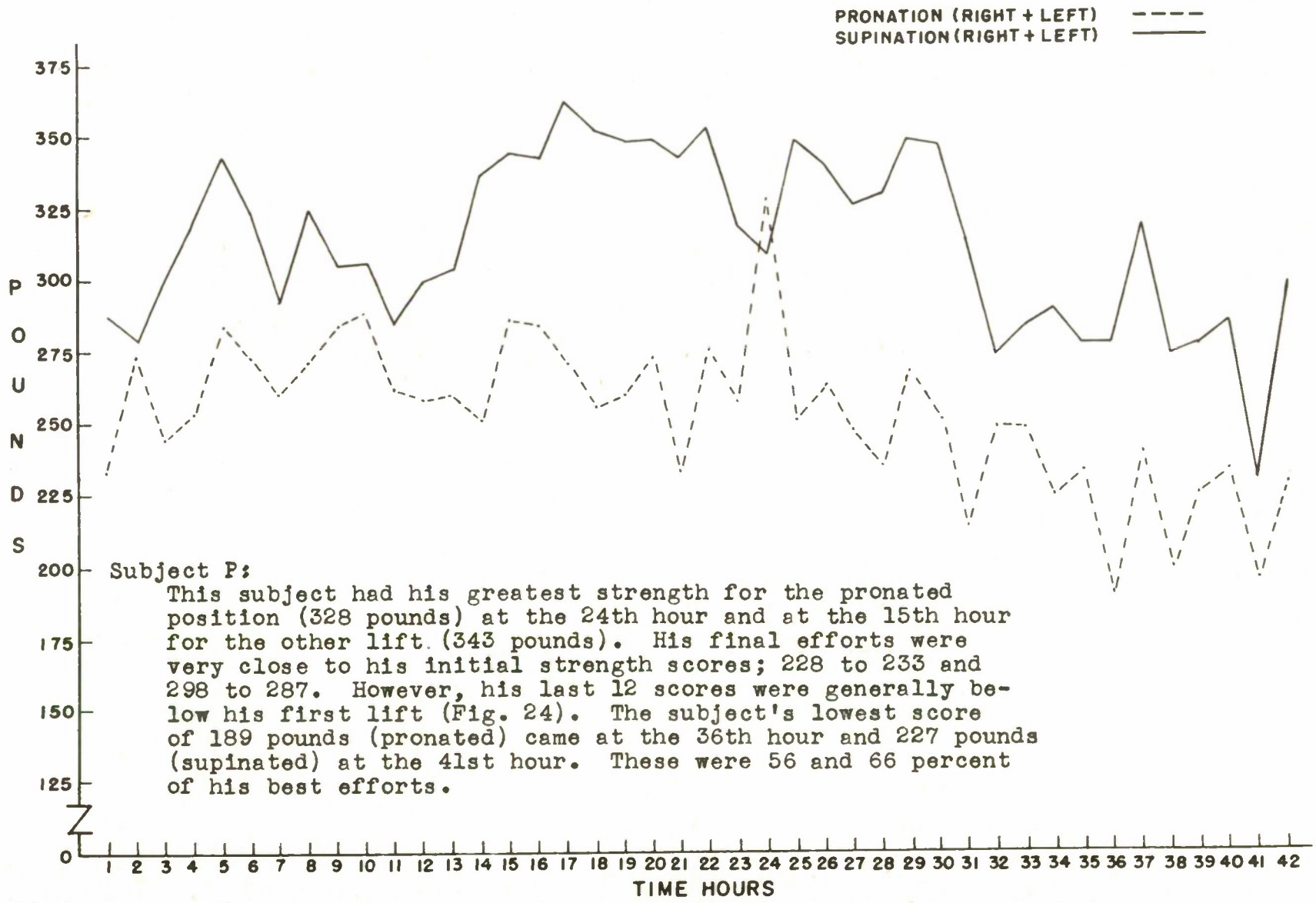


Fig. 23
STRENGTH DECREMENT
WITH FATIGUE
(SUBJECT L )




Subject L:
The largest fluctuations in test scores appeared in this series of data (Fig. 23). Although the pronation and supination readings ran fairly parallel the variance was large. The subject started with scores of 256 (pronation) and 319 (supination) pounds. His highest peak for the pronated position was reached at 16 hours and reached 342 pounds. His strength in the supinated position was fairly high at this time but did not reach its maximum of 378 pounds until the 25th hour. At the 40th hour his test score for the pronated position was 149 pounds. The pattern for this man was quite erratic although there were signs of a decline toward the end of the test period.

Fig. 24
STRENGTH DECREMENT
WITH FATIGUE
(SUBJECT P )




Subject P:
This subject had his greatest strength for the pronated position (328 pounds) at the 24th hour and at the 15th hour for the other lift (343 pounds). His final efforts were very close to his initial strength scores; 228 to 233 and 298 to 287. However, his last 12 scores were generally below his first lift (Fig. 24). The subject's lowest score of 189 pounds (pronated) came at the 36th hour and 227 pounds (supinated) at the 41st hour. These were 56 and 66 percent of his best efforts.

Fig. 25
STRENGTH DECREMENT
WITH FATIGUE
(SUBJECT S )

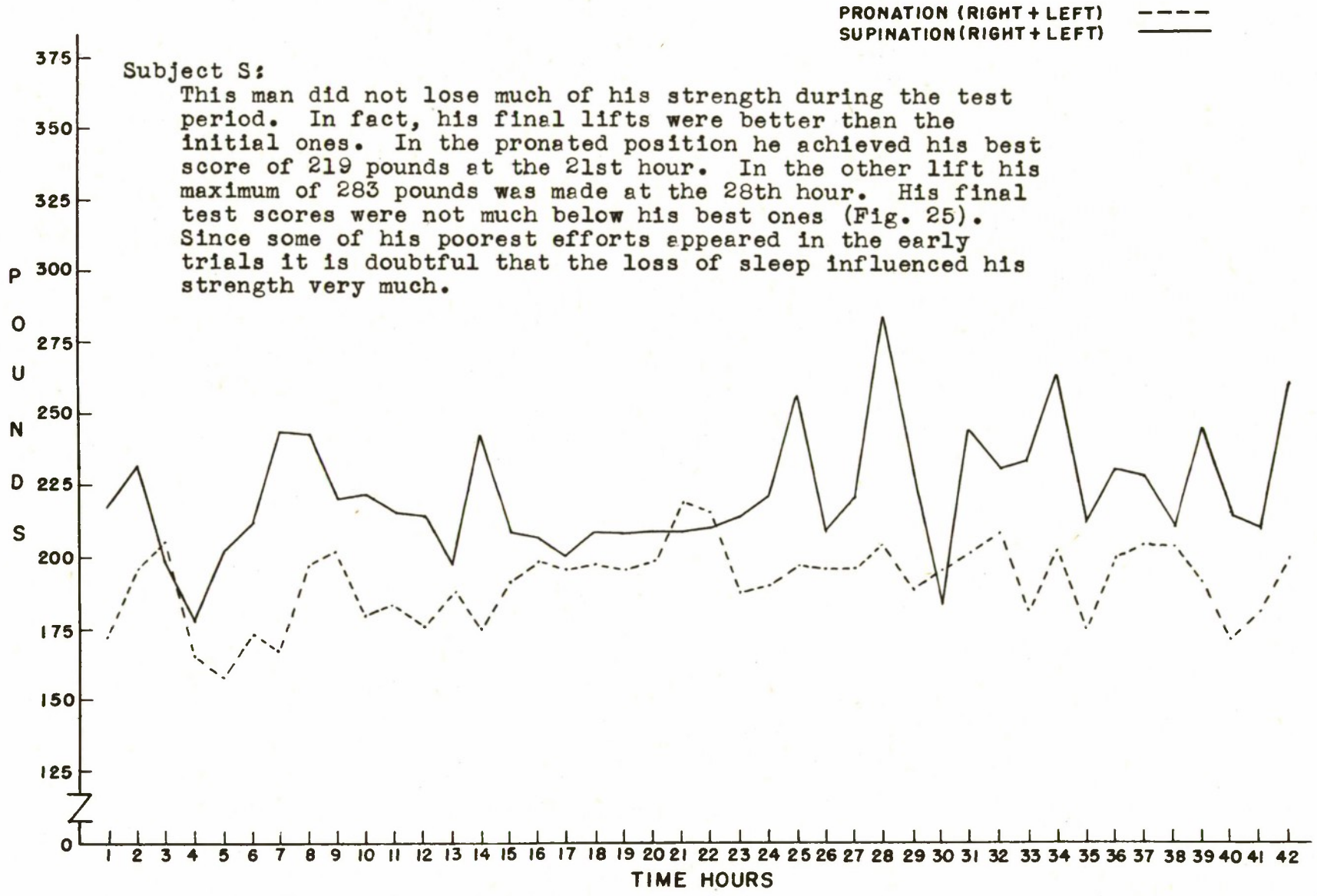
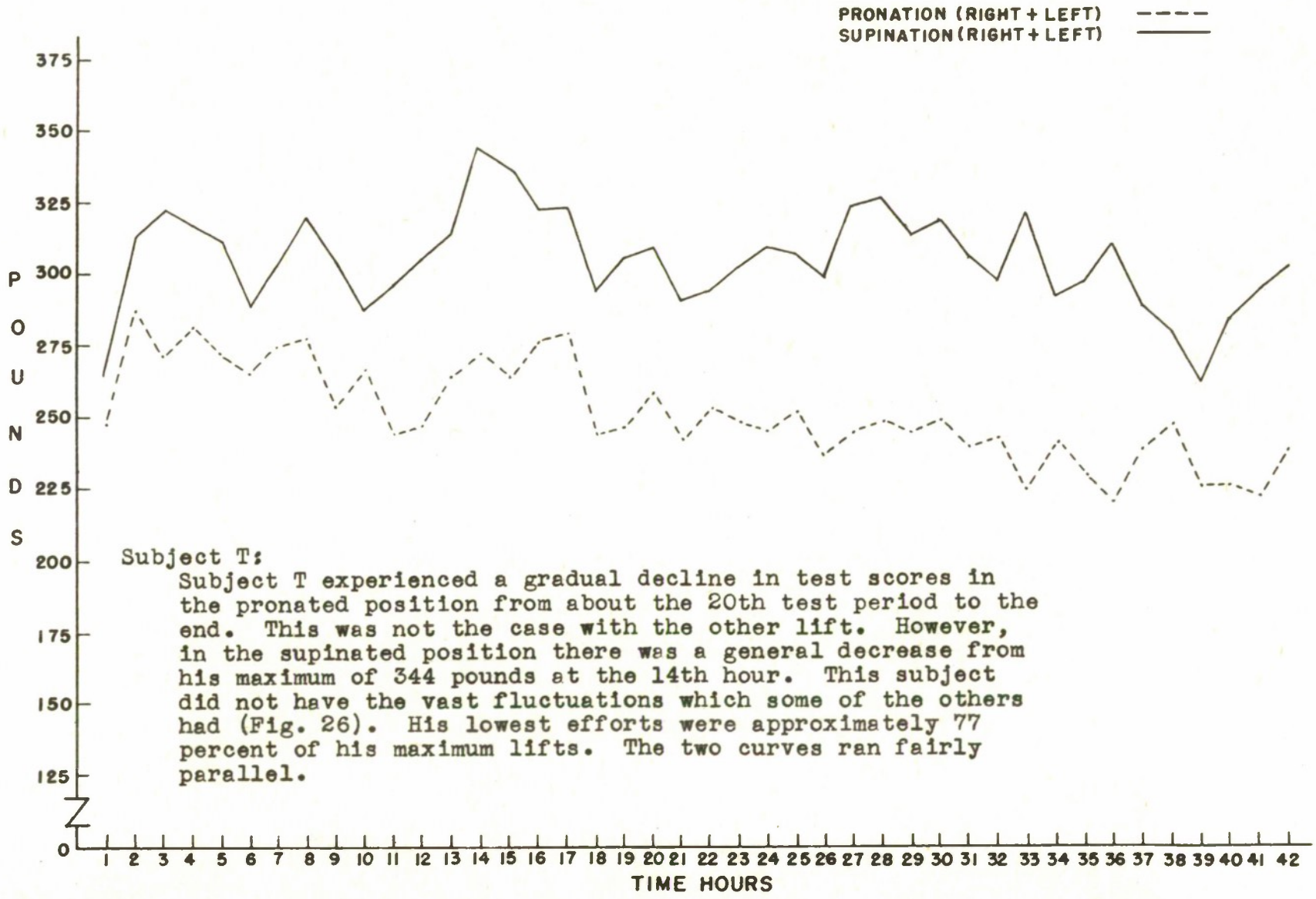


Fig. 26
STRENGTH DECREMENT
WITH FATIGUE
(SUBJECT T )




Subject T:
Subject T experienced a gradual decline in test scores in the pronated position from about the 20th test period to the end. This was not the case with the other lift. However, in the supinated position there was a general decrease from his maximum of 344 pounds at the 14th hour. This subject did not have the vast fluctuations which some of the others had (Fig. 26). His lowest efforts were approximately 77 percent of his maximum lifts. The two curves ran fairly parallel.

## SECTION VI

## SUMMARY OF FINDINGS AND RECOMMENDATIONS

The investigation was concerned with three problems and three samples of subjects were employed. The initial testing involved 30 men to determine the strength which they could exert, while seated in a simulated pilot-seat, with the arms and hands in selected positions. One hundred and twenty tests were required of each subject. Since each strength test called for three exposures a total of 10,800 resultants were calculated as a basis for describing these data. The second phase of the research called for four tests on 25 subjects and information was gathered on human strength in wrist pronation and wrist supination. The final test period was designed to ascertain the strength decrement over a 42-hour period. Each of the six subjects was given four tests every hour during the test period. From these data the following conclusions may be drawn:

1. With the subject in a sitting position a greater amount of strength could be exerted with the wrists in a supinated position than in the pronated position. The one exception was in adduction. In the forward, back, up, down and abducted movements the supinated position was superior by an average of 14 percent.

2. In examining the data for maximum values and degrees of elbow flexion, 16 maximum strength scores were attained at 60° of flexion; 1 at 120; 5 at 150; and 2 at 180°.

3. The mean values for any particular movement were influenced by the degrees of elbow flexion. The average reduction between the maximum and minimum strength score for a particular elbow position was 40 percent. That is, the minimum mean value was 60 percent of the maximum mean.

4. A study of the extreme scores indicated that on the average the maximum score was 5.3 times larger with the wrists pronated and 6.1 times greater in the supinated position than the minimum strength scores. It was once again apparent that there are tremendous differences in human strength and that some people are capable of exerting 10 times as much strength as their fellow-man.

5. In general the right side was stronger than the left and the average in these cases was about 10 percent. In three instances the left side averaged 5 percent more than the right.

6. The curves for the right and left arms, relating strength with elbow position, closely paralleled each other in practically all movements.

7. With the subject in the sitting position the three strongest movements were the lift up, push forward and push down. The same order held for both the right and left arms and for the supinated as well as the pronated positions. The other three actions, back pull, abduction and adduction were, in general, less

than half as strong.

8. Wrist pronation and supination were moderately strong movements and the differences between the right and left hands were slight.

9. An examination of the strength-decrement data covering the 42-hour test period indicated that in general there was a falling-off in strength but that it was possible for a subject to marshal sufficient reserve strength for a single maximum effort that was called for in this research to attain a value that was as good as his initial test. In a number of instances the final score was actually better than the first. But the general pattern was a decline during the latter stages of the test period.

Recommendations

The following recommendations seem appropriate:

1. This report and the previous one by the author (7) give a fair amount of information regarding arm strength and it might be timely to investigate leg strength.

2. In designing hand levers that are at the side of a pilot and where the pilot's arms are extended vertically down and in a perpendicular line with the external canthus, it should be remembered that the maximum strength in a forward push, back pull, abduction and adduction can be applied with the elbows at $60^{\circ}$ flexion. A lever requiring a lift up or push down might better be fixed so the elbows are between 150 and $180^{\circ}$.

3. With the wrists in line with the external canthus leverage systems that call for a strong movement should operate from a forward push, a lift up or a downward push.

4. The subject of fatigue should be further explored. It might prove fruitful to design a research which imposes a constant muscular stress of a low magnitude on a subject and observe the strength decrement under these conditions.

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## APPENDIX A
## CALIBRATION FOR RIGHT DYNAMOMETER
## (X-X Axis)

| Pounds | Dial Reading | | Pounds | Dial Reading | |
|---|---|---|---|---|---|
| 5 | -9.63 | 0.39 | 53 | -7.18 | 2.72 |
| 6 | -9.58 | 0.43 | 54 | -7.13 | 2.76 |
| 7 | -9.53 | 0.47 | 55 | -7.08 | 2.80 |
| 8 | -9.48 | 0.51 | 56 | -7.04 | 2.85 |
| 9 | -9.43 | 0.55 | 57 | -7.00 | 2.91 |
| 10 | -9.37 | 0.60 | 58 | -6.96 | 2.97 |
| 11 | -9.33 | 0.65 | 59 | -6.92 | 3.03 |
| 12 | -9.28 | 0.70 | 60 | -6.88 | 3.09 |
| 13 | -9.23 | 0.72 | 61 | -6.82 | 3.14 |
| 14 | -9.18 | 0.75 | 62 | -6.76 | 3.18 |
| 15 | -9.14 | 0.85 | 63 | -6.70 | 3.22 |
| 16 | -9.09 | 0.90 | 64 | -6.65 | 3.26 |
| 17 | -9.03 | 0.95 | 65 | -6.60 | 3.30 |
| 18 | -8.98 | 0.99 | 66 | -6.54 | 3.35 |
| 19 | -8.93 | 1.04 | 67 | -6.48 | 3.40 |
| 20 | -8.88 | 1.09 | 68 | -6.42 | 3.45 |
| 21 | -8.83 | 1.14 | 69 | -6.37 | 3.50 |
| 22 | -8.79 | 1.19 | 70 | -6.31 | 3.55 |
| 23 | -8.75 | 1.23 | 71 | -6.27 | 3.61 |
| 24 | -8.71 | 1.28 | 72 | -6.23 | 3.66 |
| 25 | -8.67 | 1.32 | 73 | -6.19 | 3.71 |
| 26 | -8.61 | 1.36 | 74 | -6.16 | 3.76 |
| 27 | -8.55 | 1.40 | 75 | -6.13 | 3.81 |
| 28 | -8.49 | 1.44 | 76 | -6.07 | 3.87 |
| 29 | -8.43 | 1.48 | 77 | -6.01 | 3.93 |
| 30 | -8.38 | 1.53 | 78 | -5.95 | 3.98 |
| 31 | -8.33 | 1.59 | 79 | -5.90 | 4.03 |
| 32 | -8.28 | 1.64 | 80 | -5.85 | 4.08 |
| 33 | -8.23 | 1.69 | 81 | -5.80 | 4.12 |
| 34 | -8.18 | 1.74 | 82 | -5.75 | 4.16 |
| 35 | -8.13 | 1.79 | 83 | -5.70 | 4.21 |
| 36 | -8.07 | 1.86 | 84 | -5.65 | 4.25 |
| 37 | -8.01 | 1.93 | 85 | -5.60 | 4.30 |
| 38 | -7.96 | 1.99 | 86 | -5.58 | 4.36 |
| 39 | -7.91 | 2.06 | 87 | -5.55 | 4.42 |
| 40 | -7.85 | 2.12 | 88 | -5.53 | 4.48 |
| 41 | -7.80 | 2.15 | 89 | -5.51 | 4.54 |
| 42 | -7.76 | 2.18 | 90 | -5.49 | 4.60 |
| 43 | -7.71 | 2.21 | 91 | -5.41 | 4.65 |
| 44 | -7.66 | 2.25 | 92 | -5.34 | 4.70 |
| 45 | -7.62 | 2.29 | 93 | -5.27 | 4.74 |
| 46 | -7.56 | 2.35 | 94 | -5.20 | 4.78 |
| 47 | -7.50 | 2.41 | 95 | -5.12 | 4.83 |
| 48 | -7.45 | 2.47 | 96 | -5.07 | 4.88 |
| 49 | -7.40 | 2.53 | 97 | -5.02 | 4.93 |
| 50 | -7.35 | 2.58 | 98 | -4.97 | 4.98 |
| 51 | -7.29 | 2.63 | 99 | -4.92 | 5.03 |
| 52 | -7.23 | 2.67 | 100 | -4.87 | 5.07 |

| Pounds | Dial Reading | | Pounds | Dial Reading | |
|---|---|---|---|---|---|
| 101 | -4.81 | 5.15 | 136 | -3.19 | 6.95 |
| 102 | -4.76 | 5.23 | 137 | -3.13 | 7.02 |
| 103 | -4.71 | 5.31 | 138 | -3.07 | 7.09 |
| 104 | -4.66 | 5.38 | 139 | -3.02 | 7.15 |
| 105 | -4.61 | 5.45 | 140 | -2.97 | 7.21 |
| 106 | -4.56 | 5.49 | 141 | -2.92 | 7.23 |
| 107 | -4.52 | 5.53 | 142 | -2.87 | 7.25 |
| 108 | -4.48 | 5.56 | 143 | -2.82 | 7.27 |
| 109 | -4.43 | 5.59 | 144 | -2.77 | 7.29 |
| 110 | -4.38 | 5.62 | 145 | -2.73 | 7.32 |
| 111 | -4.34 | 5.66 | 146 | -2.68 | 7.39 |
| 112 | -4.31 | 5.70 | 147 | -2.63 | 7.45 |
| 113 | -4.28 | 5.74 | 148 | -2.59 | 7.52 |
| 114 | -4.25 | 5.78 | 149 | -2.55 | 7.59 |
| 115 | -4.22 | 5.82 | 150 | -2.50 | 7.65 |
| 116 | -4.16 | 5.88 | 151 | -2.45 | 7.71 |
| 117 | -4.10 | 5.94 | 152 | -2.40 | 7.77 |
| 118 | -4.04 | 6.00 | 153 | -2.35 | 7.83 |
| 119 | -3.98 | 6.06 | 154 | -2.30 | 7.85 |
| 120 | -3.92 | 6.12 | 155 | -2.25 | 7.95 |
| 121 | -3.88 | 6.17 | 156 | -2.20 | 8.00 |
| 122 | -3.84 | 6.22 | 157 | -2.15 | 8.05 |
| 123 | -3.80 | 6.27 | 158 | -2.10 | 8.10 |
| 124 | -3.77 | 6.31 | 159 | -2.05 | 8.15 |
| 125 | -3.74 | 6.35 | 160 | -2.00 | 8.20 |
| 126 | -3.68 | 6.41 | 161 | -1.95 | 8.26 |
| 127 | -3.62 | 6.47 | 162 | -1.90 | 8.32 |
| 128 | -3.56 | 6.52 | 163 | -1.85 | 8.38 |
| 129 | -3.50 | 6.57 | 164 | -1.80 | 8.44 |
| 130 | -3.45 | 6.62 | 165 | -1.75 | 8.50 |
| 131 | -3.41 | 6.68 | 166 | -1.70 | 8.55 |
| 132 | -3.37 | 6.73 | 167 | -1.65 | 8.60 |
| 133 | -3.33 | 6.78 | 168 | -1.60 | 8.65 |
| 134 | -3.29 | 6.83 | 169 | -1.55 | 8.70 |
| 135 | -3.25 | 6.88 | 170 | -1.50 | 8.75 |

## APPENDIX B
## CALIBRATION FOR RIGHT DYNAMOMETER
## (Y-Y Axis)

| Pounds | Dial Reading | | Pounds | Dial Reading | |
|---|---|---|---|---|---|
| 5 | -9.75 | 0.31 | 53 | -7.25 | 2.87 |
| 6 | -9.70 | 0.37 | 54 | -7.20 | 2.93 |
| 7 | -9.64 | 0.43 | 55 | -7.15 | 2.99 |
| 8 | -9.57 | 0.48 | 56 | -7.10 | 3.04 |
| 9 | -9.52 | 0.53 | 57 | -7.05 | 3.08 |
| 10 | -9.47 | 0.58 | 58 | -7.00 | 3.12 |
| 11 | -9.41 | 0.64 | 59 | -6.95 | 3.16 |
| 12 | -9.34 | 0.70 | 60 | -6.90 | 3.20 |
| 13 | -9.28 | 0.76 | 61 | -6.85 | 3.25 |
| 14 | -9.21 | 0.82 | 62 | -6.80 | 3.30 |
| 15 | -9.15 | 0.88 | 63 | -6.75 | 3.34 |
| 16 | -9.10 | 0.92 | 64 | -6.70 | 3.38 |
| 17 | -9.05 | 0.96 | 65 | -6.66 | 3.42 |
| 18 | -9.00 | 0.99 | 66 | -6.61 | 3.47 |
| 19 | -8.95 | 1.02 | 67 | -6.56 | 3.51 |
| 20 | -8.90 | 1.05 | 68 | -6.51 | 3.56 |
| 21 | -8.84 | 1.11 | 69 | -6.46 | 3.61 |
| 22 | -8.78 | 1.17 | 70 | -6.42 | 3.65 |
| 23 | -8.72 | 1.23 | 71 | -6.37 | 3.70 |
| 24 | -8.66 | 1.29 | 72 | -6.32 | 3.74 |
| 25 | -8.60 | 1.35 | 73 | -6.27 | 3.79 |
| 26 | -8.56 | 1.41 | 74 | -6.22 | 3.83 |
| 27 | -8.51 | 1.47 | 75 | -6.16 | 3.87 |
| 28 | -8.46 | 1.52 | 76 | -6.10 | 3.93 |
| 29 | -8.41 | 1.57 | 77 | -6.05 | 3.99 |
| 30 | -8.36 | 1.62 | 78 | -6.00 | 4.05 |
| 31 | -8.30 | 1.66 | 79 | -5.95 | 4.10 |
| 32 | -8.25 | 1.69 | 80 | -5.90 | 4.15 |
| 33 | -8.20 | 1.72 | 81 | -5.84 | 4.20 |
| 34 | -8.15 | 1.75 | 82 | -5.78 | 4.25 |
| 35 | -8.10 | 1.78 | 83 | -5.72 | 4.30 |
| 36 | -8.06 | 1.85 | 84 | -5.67 | 4.35 |
| 37 | -8.02 | 1.92 | 85 | -5.62 | 4.39 |
| 38 | -7.98 | 1.98 | 86 | -5.56 | 4.44 |
| 39 | -7.94 | 2.05 | 87 | -5.50 | 4.49 |
| 40 | -7.90 | 2.12 | 88 | -5.45 | 4.53 |
| 41 | -7.85 | 2.18 | 89 | -5.40 | 4.57 |
| 42 | -7.79 | 2.24 | 90 | -5.35 | 4.61 |
| 43 | -7.72 | 2.30 | 91 | -5.30 | 4.66 |
| 44 | -7.67 | 2.36 | 92 | -5.25 | 4.71 |
| 45 | -7.62 | 2.42 | 93 | -5.20 | 4.76 |
| 46 | -7.58 | 2.48 | 94 | -5.16 | 4.81 |
| 47 | -7.53 | 2.54 | 95 | -5.12 | 4.85 |
| 48 | -7.49 | 2.59 | 96 | -5.07 | 4.91 |
| 49 | -7.44 | 2.64 | 97 | -5.02 | 4.96 |
| 50 | -7.40 | 2.69 | 98 | -4.98 | 5.01 |
| 51 | -7.35 | 2.75 | 99 | -4.94 | 5.06 |
| 52 | -7.30 | 2.81 | 100 | -4.90 | 5.11 |

APPENDIX B
(Cont'd)

| Pounds | Dial Reading | | Pounds | Dial Reading | |
|---|---|---|---|---|---|
| 101 | -4.85 | 5.18 | 114 | -4.20 | 5.74 |
| 102 | -4.80 | 5.25 | 115 | -4.16 | 5.80 |
| 103 | -4.75 | 5.32 | 116 | -4.11 | 5.85 |
| 104 | -4.70 | 5.39 | 117 | -4.06 | 5.89 |
| 105 | -4.65 | 5.45 | 118 | -4.01 | 5.93 |
| 106 | -4.60 | 5.47 | 119 | -3.96 | 5.97 |
| 107 | -4.55 | 5.49 | 120 | -3.92 | 6.02 |
| 108 | -4.50 | 5.51 | 121 | -3.87 | 6.06 |
| 109 | -4.45 | 5.52 | 122 | -3.82 | 6.10 |
| 110 | -4.40 | 5.54 | 123 | -3.77 | 6.13 |
| 111 | -4.35 | 5.59 | 124 | -3.72 | 6.16 |
| 112 | -4.30 | 5.64 | 125 | -3.68 | 6.19 |
| 113 | -4.25 | 5.69 | | | |

## APPENDIX C
## CALIBRATION FOR RIGHT DYNAMOMETER
## (Z-Z Axis)

| Pounds | Dial Reading | | Pounds | Dial Reading | |
|---|---|---|---|---|---|
| 5 | -9.25 | 0.71 | 53 | -4.53 | 5.49 |
| 6 | -9.14 | 0.82 | 54 | -4.45 | 5.59 |
| 7 | -9.03 | 0.94 | 55 | -4.38 | 5.69 |
| 8 | -8.93 | 1.05 | 56 | -4.30 | 5.79 |
| 9 | -8.82 | 1.16 | 57 | -4.22 | 5.88 |
| 10 | -8.72 | 1.28 | 58 | -4.15 | 5.97 |
| 11 | -8.61 | 1.39 | 59 | -4.07 | 6.06 |
| 12 | -8.49 | 1.51 | 60 | -4.00 | 6.15 |
| 13 | -8.38 | 1.62 | 61 | -3.91 | 6.26 |
| 14 | -8.26 | 1.73 | 62 | -3.82 | 6.36 |
| 15 | -8.15 | 1.85 | 63 | -3.74 | 6.46 |
| 16 | -8.04 | 1.94 | 64 | -3.66 | 6.56 |
| 17 | -7.93 | 2.03 | 65 | -3.58 | 6.66 |
| 18 | -7.83 | 2.12 | 66 | -3.52 | 6.77 |
| 19 | -7.73 | 2.21 | 67 | -3.45 | 6.87 |
| 20 | -7.63 | 2.30 | 68 | -3.39 | 6.97 |
| 21 | -7.52 | 2.40 | 69 | -3.33 | 7.07 |
| 22 | -7.42 | 2.50 | 70 | -3.27 | 7.17 |
| 23 | -7.32 | 2.60 | 71 | -3.18 | 7.28 |
| 24 | -7.22 | 2.70 | 72 | -3.09 | 7.39 |
| 25 | -7.12 | 2.80 | 73 | -3.00 | 7.50 |
| 26 | -7.01 | 2.90 | 74 | -2.90 | 7.60 |
| 27 | -6.91 | 3.00 | 75 | -2.81 | 7.70 |
| 28 | -6.81 | 3.09 | 76 | -2.70 | 7.79 |
| 29 | -6.71 | 3.19 | 77 | -2.59 | 7.88 |
| 30 | -6.61 | 3.29 | 78 | -2.48 | 7.97 |
| 31 | -6.50 | 3.39 | 79 | -2.38 | 8.06 |
| 32 | -6.38 | 3.48 | 80 | -2.28 | 8.15 |
| 33 | -6.27 | 3.57 | 81 | -2.19 | 8.25 |
| 34 | -6.16 | 3.66 | 82 | -2.10 | 8.35 |
| 35 | -6.05 | 3.75 | 83 | -2.02 | 8.44 |
| 36 | -5.94 | 3.84 | 84 | -1.94 | 8.53 |
| 37 | -5.83 | 3.93 | 85 | -1.85 | 8.62 |
| 38 | -5.72 | 4.02 | 86 | -1.76 | 8.72 |
| 39 | -5.62 | 4.11 | 87 | -1.67 | 8.82 |
| 40 | -5.52 | 4.20 | 88 | -1.59 | 8.92 |
| 41 | -5.47 | 4.31 | 89 | -1.51 | 9.02 |
| 42 | -5.41 | 4.42 | 90 | -1.42 | 9.12 |
| 43 | -5.35 | 4.52 | 91 | -1.28 | 9.21 |
| 44 | -5.30 | 4.63 | 92 | -1.14 | 9.30 |
| 45 | -5.25 | 4.73 | 93 | -1.00 | 9.39 |
| 46 | -5.15 | 4.82 | 94 | -0.86 | 9.47 |
| 47 | -5.05 | 4.91 | 95 | -0.72 | 9.55 |
| 48 | -4.95 | 5.01 | 96 | -0.62 | 9.64 |
| 49 | -4.85 | 5.11 | 97 | -0.52 | 9.73 |
| 50 | -4.75 | 5.21 | 98 | -0.42 | 9.82 |
| 51 | -4.68 | 5.30 | 99 | -0.32 | 9.91 |
| 52 | -4.60 | 5.39 | 100 | -0.21 | 9.99 |

## APPENDIX D
## CALIBRATION FOR LEFT DYNAMOMETER
## (X-X Axis)

| Pounds | Dial Reading | | Pounds | Dial Reading | |
|---|---|---|---|---|---|
| 5 | -9.63 | 0.45 | 53 | -6.89 | 3.08 |
| 6 | -9.57 | 0.50 | 54 | -6.81 | 3.14 |
| 7 | -9.50 | 0.55 | 55 | -6.73 | 3.20 |
| 8 | -9.43 | 0.60 | 56 | -6.67 | 3.26 |
| 9 | -9.36 | 0.65 | 57 | -6.61 | 3.32 |
| 10 | -9.29 | 0.69 | 58 | -6.55 | 3.38 |
| 11 | -9.23 | 0.74 | 59 | -6.49 | 3.44 |
| 12 | -9.17 | 0.79 | 60 | -6.42 | 3.50 |
| 13 | -9.11 | 0.84 | 61 | -6.37 | 3.55 |
| 14 | -9.05 | 0.89 | 62 | -6.32 | 3.60 |
| 15 | -9.00 | 0.94 | 63 | -6.27 | 3.65 |
| 16 | -8.95 | 0.98 | 64 | -6.22 | 3.70 |
| 17 | -8.90 | 1.03 | 65 | -6.18 | 3.74 |
| 18 | -8.85 | 1.08 | 66 | -6.12 | 3.79 |
| 19 | -8.79 | 1.13 | 67 | -6.07 | 3.83 |
| 20 | -8.73 | 1.18 | 68 | -6.01 | 3.87 |
| 21 | -8.66 | 1.24 | 69 | -5.95 | 3.91 |
| 22 | -8.60 | 1.30 | 70 | -5.90 | 3.95 |
| 23 | -8.53 | 1.36 | 71 | -5.78 | 4.07 |
| 24 | -8.47 | 1.42 | 72 | -5.78 | 4.07 |
| 25 | -8.41 | 1.48 | 73 | -5.72 | 4.13 |
| 26 | -8.35 | 1.52 | 74 | -5.65 | 4.19 |
| 27 | -8.30 | 1.57 | 75 | -5.60 | 4.25 |
| 28 | -8.25 | 1.62 | 76 | -5.52 | 4.30 |
| 29 | -8.20 | 1.67 | 77 | -5.45 | 4.35 |
| 30 | -8.15 | 1.72 | 78 | -5.37 | 4.40 |
| 31 | -8.10 | 1.80 | 79 | -5.30 | 4.45 |
| 32 | -8.05 | 1.88 | 80 | -5.22 | 4.50 |
| 33 | -8.00 | 1.96 | 81 | -5.17 | 4.56 |
| 34 | -7.95 | 2.04 | 82 | -5.12 | 4.62 |
| 35 | -7.89 | 2.12 | 83 | -5.06 | 4.68 |
| 36 | -7.86 | 2.17 | 84 | -5.00 | 4.74 |
| 37 | -7.82 | 2.21 | 85 | -4.95 | 4.80 |
| 38 | -7.79 | 2.25 | 86 | -4.89 | 4.85 |
| 39 | -7.76 | 2.29 | 87 | -4.82 | 4.90 |
| 40 | -7.72 | 2.33 | 88 | -4.75 | 4.95 |
| 41 | -7.67 | 2.36 | 89 | -4.68 | 5.00 |
| 42 | -7.61 | 2.42 | 90 | -4.61 | 5.05 |
| 43 | -7.56 | 2.48 | 91 | -4.57 | 5.13 |
| 44 | -7.50 | 2.54 | 92 | -4.52 | 5.20 |
| 45 | -7.45 | 2.63 | 93 | -4.48 | 5.28 |
| 46 | -7.39 | 2.69 | 94 | -4.43 | 5.35 |
| 47 | -7.33 | 2.74 | 95 | -4.39 | 5.42 |
| 48 | -7.27 | 2.79 | 96 | -4.34 | 5.47 |
| 49 | -7.21 | 2.84 | 97 | -4.29 | 5.52 |
| 50 | -7.15 | 2.89 | 98 | -4.25 | 5.56 |
| 51 | -7.07 | 2.96 | 99 | -4.20 | 5.60 |
| 52 | -6.98 | 3.02 | 100 | -4.15 | 5.65 |

APPENDIX D
(Cont'd)

| Pounds | Dial Reading | | Pounds | Dial Reading | |
|---|---|---|---|---|---|
| 101 | -4.10 | 5.71 | 136 | -2.20 | 7.58 |
| 102 | -4.05 | 5.78 | 137 | -2.15 | 7.64 |
| 103 | -4.00 | 5.84 | 138 | -2.10 | 7.69 |
| 104 | -3.95 | 5.90 | 139 | -2.05 | 7.74 |
| 105 | -3.90 | 5.95 | 140 | -1.99 | 7.80 |
| 106 | -3.84 | 6.01 | 141 | -1.93 | 7.86 |
| 107 | -3.78 | 6.08 | 142 | -1.86 | 7.92 |
| 108 | -3.72 | 6.14 | 143 | -1.80 | 7.98 |
| 109 | -3.66 | 6.21 | 144 | -1.73 | 8.04 |
| 110 | -3.60 | 6.28 | 145 | -1.67 | 8.10 |
| 111 | -3.56 | 6.33 | 146 | -1.60 | 8.16 |
| 112 | -3.52 | 6.37 | 147 | -1.54 | 8.22 |
| 113 | -3.48 | 6.41 | 148 | -1.47 | 8.28 |
| 114 | -3.44 | 6.45 | 149 | -1.41 | 8.34 |
| 115 | -3.40 | 6.50 | 150 | -1.35 | 8.42 |
| 116 | -3.34 | 6.55 | 151 | -1.29 | 8.48 |
| 117 | -3.28 | 6.60 | 152 | -1.23 | 8.54 |
| 118 | -3.22 | 6.65 | 153 | -1.17 | 8.60 |
| 119 | -3.16 | 6.70 | 154 | -1.11 | 8.66 |
| 120 | -3.10 | 6.75 | 155 | -1.05 | 8.72 |
| 121 | -3.04 | 6.80 | 156 | -0.99 | 8.78 |
| 122 | -2.98 | 6.85 | 157 | -0.93 | 8.84 |
| 123 | -2.92 | 6.90 | 158 | -0.87 | 8.90 |
| 124 | -2.86 | 6.95 | 159 | -0.81 | 8.96 |
| 125 | -2.80 | 6.99 | 160 | -0.75 | 9.12 |
| 126 | -2.76 | 7.05 | 161 | -0.69 | 9.18 |
| 127 | -2.72 | 7.11 | 162 | -0.63 | 9.24 |
| 128 | -2.68 | 7.17 | 163 | -0.57 | 9.30 |
| 129 | -2.64 | 7.23 | 164 | -0.51 | 9.36 |
| 130 | -2.60 | 7.28 | 165 | -0.45 | 9.42 |
| 131 | -2.53 | 7.33 | 166 | -0.39 | 9.48 |
| 132 | -2.46 | 7.38 | 167 | -0.33 | 9.54 |
| 133 | -2.39 | 7.43 | 168 | -0.26 | 9.60 |
| 134 | -2.32 | 7.48 | 169 | -0.21 | 9.66 |
| 135 | -2.25 | 7.53 | 170 | -0.15 | 9.72 |

## APPENDIX E
## CALIBRATION OF LEFT DYNAMOMETER
## (Y-Y Axis)

| Pounds | Dial Reading | | Pounds | Dial Reading | |
|---|---|---|---|---|---|
| 5 | -9.59 | 0.39 | 53 | -6.72 | 3.15 |
| 6 | -9.53 | 0.46 | 54 | -6.66 | 3.20 |
| 7 | -9.48 | 0.53 | 55 | -6.60 | 3.25 |
| 8 | -9.42 | 0.59 | 56 | -6.54 | 3.31 |
| 9 | -9.36 | 0.65 | 57 | -6.48 | 3.37 |
| 10 | -9.30 | 0.71 | 58 | -6.43 | 3.43 |
| 11 | -9.24 | 0.77 | 59 | -6.38 | 3.49 |
| 12 | -9.18 | 0.82 | 60 | -6.33 | 3.56 |
| 13 | -9.12 | 0.87 | 61 | -6.26 | 3.62 |
| 14 | -9.06 | 0.92 | 62 | -6.20 | 3.67 |
| 15 | -9.00 | 0.98 | 63 | -6.13 | 3.73 |
| 16 | -8.94 | 1.04 | 64 | -6.06 | 3.79 |
| 17 | -8.88 | 1.09 | 65 | -6.00 | 3.85 |
| 18 | -8.83 | 1.15 | 66 | -5.95 | 3.91 |
| 19 | -8.87 | 1.20 | 67 | -5.89 | 3.97 |
| 20 | -8.72 | 1.25 | 68 | -5.83 | 4.03 |
| 21 | -8.66 | 1.30 | 69 | -5.78 | 4.08 |
| 22 | -8.60 | 1.35 | 70 | -5.72 | 4.14 |
| 23 | -8.54 | 1.40 | 71 | -5.66 | 4.20 |
| 24 | -8.48 | 1.45 | 72 | -5.60 | 4.27 |
| 25 | -8.42 | 1.50 | 73 | -5.55 | 4.33 |
| 26 | -8.36 | 1.56 | 74 | -5.50 | 4.39 |
| 27 | -8.30 | 1.62 | 75 | -5.44 | 4.45 |
| 28 | -8.23 | 1.68 | 76 | -5.38 | 4.51 |
| 29 | -8.16 | 1.74 | 77 | -5.32 | 4.57 |
| 30 | -8.10 | 1.80 | 78 | -5.26 | 4.63 |
| 31 | -8.04 | 1.86 | 79 | -5.20 | 4.69 |
| 32 | -7.99 | 1.92 | 80 | -5.13 | 4.74 |
| 33 | -7.93 | 1.98 | 81 | -5.06 | 4.81 |
| 34 | -7.87 | 2.04 | 82 | -4.99 | 4.88 |
| 35 | -7.82 | 2.10 | 83 | -4.93 | 4.95 |
| 36 | -7.76 | 2.17 | 84 | -4.86 | 5.03 |
| 37 | -7.71 | 2.24 | 85 | -4.80 | 5.10 |
| 38 | -7.65 | 2.31 | 86 | -4.76 | 5.14 |
| 39 | -7.60 | 2.38 | 87 | -4.72 | 5.19 |
| 40 | -7.55 | 2.45 | 88 | -4.68 | 5.23 |
| 41 | -7.48 | 2.51 | 89 | -4.64 | 5.27 |
| 42 | -7.41 | 2.57 | 90 | -4.60 | 5.31 |
| 43 | -7.34 | 2.62 | 91 | -4.54 | 5.37 |
| 44 | -7.27 | 2.67 | 92 | -4.48 | 5.43 |
| 45 | -7.20 | 2.72 | 93 | -4.42 | 5.49 |
| 46 | -7.14 | 2.78 | 94 | -4.36 | 5.55 |
| 47 | -7.08 | 2.83 | 95 | -4.30 | 5.61 |
| 48 | -7.02 | 2.89 | 96 | -4.23 | 5.67 |
| 49 | -6.96 | 2.95 | 97 | -4.17 | 5.72 |
| 50 | -6.90 | 3.00 | 98 | -4.11 | 5.78 |
| 51 | -6.84 | 3.05 | 99 | -4.05 | 5.83 |
| 52 | -6.78 | 3.10 | 100 | -3.98 | 5.89 |

APPENDIX E
(Cont'd)

| Pounds | Dial Reading | | Pounds | Dial Reading | |
|---|---|---|---|---|---|
| 101 | -3.92 | 5.95 | 114 | -3.09 | 6.70 |
| 102 | -3.86 | 6.01 | 115 | -3.02 | 6.75 |
| 103 | -3.80 | 6.07 | 116 | -2.97 | 6.81 |
| 104 | -3.74 | 6.13 | 117 | -2.92 | 6.87 |
| 105 | -3.68 | 6.20 | 118 | -2.87 | 6.93 |
| 106 | -3.61 | 6.25 | 119 | -2.82 | 6.99 |
| 107 | -3.54 | 6.30 | 120 | -2.77 | 7.05 |
| 108 | -3.48 | 6.35 | 121 | -2.70 | 7.10 |
| 109 | -3.42 | 6.40 | 122 | -2.63 | 7.15 |
| 110 | -3.35 | 6.44 | 123 | -2.57 | 7.20 |
| 111 | -3.28 | 6.51 | 124 | -2.51 | 7.25 |
| 112 | -3.21 | 6.58 | 125 | -2.45 | 7.30 |
| 113 | -3.15 | 6.64 | | | |

## APPENDIX F
## CALIBRATION OF LEFT DYNAMOMETER
## (Z-Z Axis)

| Pounds | Dial Reading | | Pounds | Dial Reading | |
|---|---|---|---|---|---|
| 5 | -9.25 | 0.71 | 46 | -4.52 | 5.31 |
| 6 | -9.15 | 0.83 | 47 | -4.44 | 5.42 |
| 7 | -9.05 | 0.94 | 48 | -4.36 | 5.53 |
| 8 | -8.95 | 1.06 | 49 | -4.28 | 5.64 |
| 9 | -8.85 | 1.17 | 50 | -4.20 | 5.75 |
| 10 | -8.75 | 1.29 | 51 | -4.07 | 5.86 |
| 11 | -8.63 | 1.41 | 52 | -3.94 | 5.96 |
| 12 | -8.50 | 1.53 | 53 | -3.81 | 6.07 |
| 13 | -8.37 | 1.65 | 54 | -3.68 | 6.17 |
| 14 | -8.24 | 1.77 | 55 | -3.55 | 6.28 |
| 15 | -8.11 | 1.89 | 56 | -3.47 | 6.40 |
| 16 | -8.00 | 1.98 | 57 | -3.39 | 6.51 |
| 17 | -7.89 | 2.09 | 58 | -3.31 | 6.63 |
| 18 | -7.78 | 2.19 | 59 | -3.23 | 6.75 |
| 19 | -7.66 | 2.29 | 60 | -3.15 | 6.87 |
| 20 | -7.55 | 2.38 | 61 | -3.02 | 6.98 |
| 21 | -7.44 | 2.50 | 62 | -2.89 | 7.08 |
| 22 | -7.33 | 2.63 | 63 | -2.75 | 7.18 |
| 23 | -7.22 | 2.76 | 64 | -2.63 | 7.28 |
| 24 | -7.11 | 2.88 | 65 | -2.52 | 7.38 |
| 25 | -6.99 | 3.00 | 66 | -2.41 | 7.48 |
| 26 | -6.90 | 3.07 | 67 | -2.31 | 7.59 |
| 27 | -6.80 | 3.14 | 68 | -2.20 | 7.60 |
| 28 | -6.71 | 3.21 | 69 | -2.10 | 7.71 |
| 29 | -6.62 | 3.28 | 70 | -2.00 | 7.92 |
| 30 | -6.53 | 3.35 | 71 | -1.84 | 8.04 |
| 31 | -6.41 | 3.48 | 72 | -1.69 | 8.15 |
| 32 | -6.29 | 3.60 | 73 | -1.53 | 8.27 |
| 33 | -6.17 | 3.73 | 74 | -1.38 | 8.38 |
| 34 | -6.06 | 3.86 | 75 | -1.23 | 8.50 |
| 35 | -5.96 | 3.99 | 76 | -1.13 | 8.58 |
| 36 | -5.82 | 4.12 | 77 | -1.02 | 8.66 |
| 37 | -5.67 | 4.25 | 78 | -0.92 | 8.74 |
| 38 | -5.53 | 4.38 | 79 | -0.82 | 8.82 |
| 39 | -5.38 | 4.50 | 80 | -0.72 | 8.90 |
| 40 | -5.24 | 4.62 | 81 | -0.62 | 8.98 |
| 41 | -5.11 | 4.74 | 82 | -0.52 | 9.06 |
| 42 | -4.98 | 4.86 | 83 | -0.42 | 9.14 |
| 43 | -4.86 | 4.97 | 84 | -0.32 | 9.22 |
| 44 | -4.74 | 5.08 | 85 | -0.22 | 9.30 |
| 45 | -4.61 | 5.20 | | | |

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AD-131 088

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A STUDY OF MUSCLE FORCES AND FATIGUE, by Paul A. Hunsicker. December 1957. 47p. incl. illus., 15 refs. (Proj. 7214; Task 71727) (WADC TR 57-586) (Contract AF 33(616)-3461)
Unclassified report

The first phase of the research deals with the strength test results taken on 30 subjects, covering 120 strength tests. The subjects were seated in a simulated pilot-seat, and six movements were tested. The results are presented in percentile tables and graphic

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form. The next part of the study involves data on 25 subjects who were tested to determine the amount of strength possible in wrist pronation and wrist supination. The final phase of the research gives information on the strength-decrement over a 42-hour period in which the subjects were tested hourly. Several recommendations are offered.

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